SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Gas Analyzer for Digestion Studies—**Grune et al.**

Dissolved Oxygen by Colorimetry—**Oulman and Baumann**

Oxidation of Refinery Wastes—**Elkin et al.**

New York Harbor Pollution—**Romer**

Sludge Filtration Variables—**Schepman and Cornell**

1956 Annual Index

DECEMBER, 1956—VOL. 28, No. 12

Notice to all Active Members of Member Associations

Your prompt payment of 1957 dues will avoid interruption in receipt of SEWAGE AND INDUSTRIAL WASTES as well as other Federation services. Undue delay may make it impossible for a complete volume of the JOURNAL to be furnished.

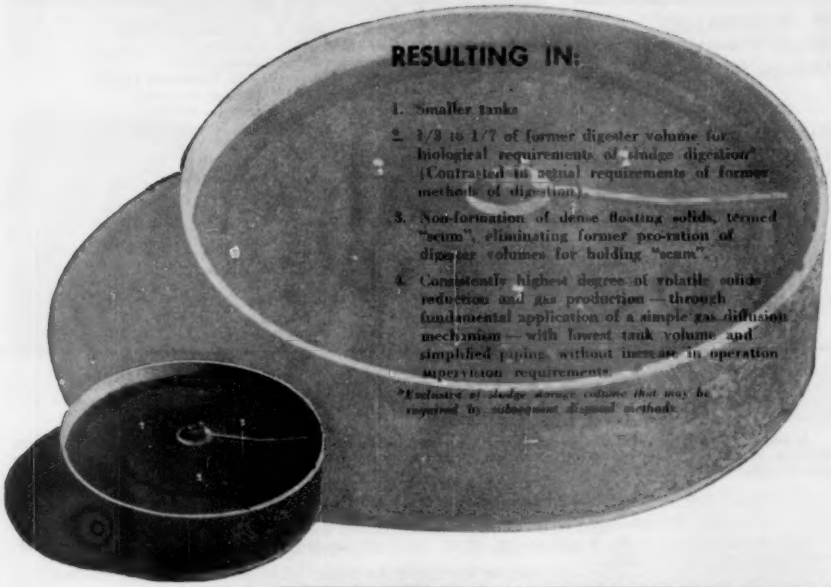
Please remit directly to your Member Association Secretary immediately upon receipt of the first dues notice from him.

CRP*

CATALYTIC
REDUCTION
PROCESS

PERMITS SMALLER TANKS . . .

through exclusively highest solids loading for sludge digestion



RESULTING IN:

1. Smaller tanks
2. 1/3 to 1/7 of former digester volume for biological requirements of sludge digestion* (Contrasted to actual requirements of former methods of digestion).
3. Non-formation of dense floating solids, termed "scum", eliminating former pro-ration of digester volumes for holding "scum".
4. Consistently highest degree of volatile solids reduction and gas production — through fundamental application of a simple gas diffusion mechanism — with lowest tank volume and simplified piping, without increase in operation supervision requirements.

*Exclusive of sludge storage volume that may be required by subsequent disposal methods.

Reports Available

Reports describing the PROCESS in detail are available on request.
Write to Department F.

*Patents Applied For

fmc

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Subsidiary of Food Machinery and Chemical Corporation

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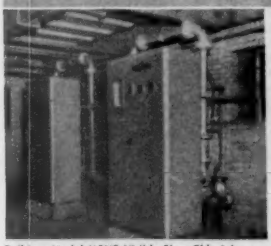
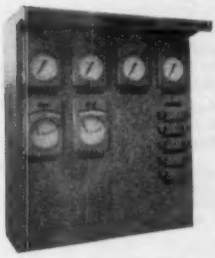
engineered specifically for sewage and waste plants . . . proven in thousands of installations



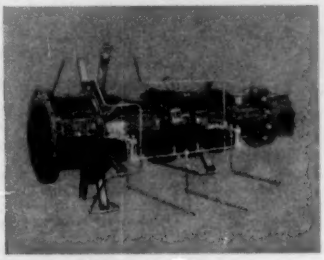
Builders Model HCVS Visible Flow Chlorinizers — capacity 100 to 8000 lbs. per 24 hrs. each — installed at Bucklin Point Sewage Treatment Plant, East Providence, Rhode Island.

Builders Chronoflo Electric Receiver for remote totalizing, indicating, and recording of raw sewage flow at Mt. Vernon, Ohio, Sewage Plant.

24" Kennison Nozzle, which, with Builders Type M Totalizer-Indicator-Recorder, meters sewage influent at Eslava Creek Sewage Disposal Plant, Mobile, Alabama.



Builders Master Control Panel at New Rochelle, N. Y., Sewage Treatment Plant.



Builders Venturi Tube with hydraulic operated vent cleaners and Flush Check System for trouble-free metering of sewage and sludge flows.

Builders Instrument Panel for Hyperion Sewage Treatment Plant at Los Angeles, Calif. . . . gauges indicate air/sewage ratio, return sludge/sewage ratio, aeration air, raw sewage, and return sludge.

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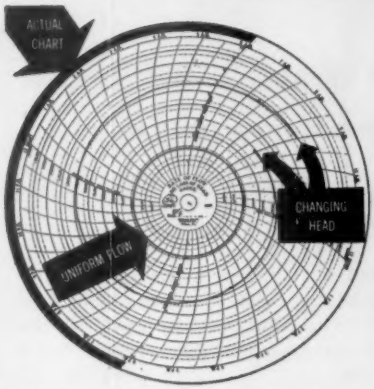
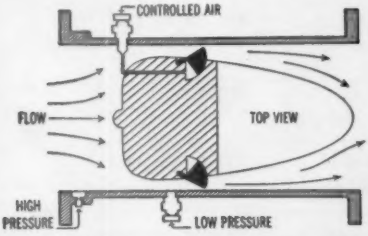
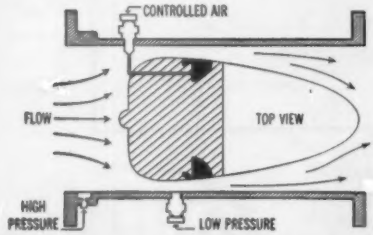
Modulair® Controller regulates plant discharges, controls elutriation...responds fast...closes tight!



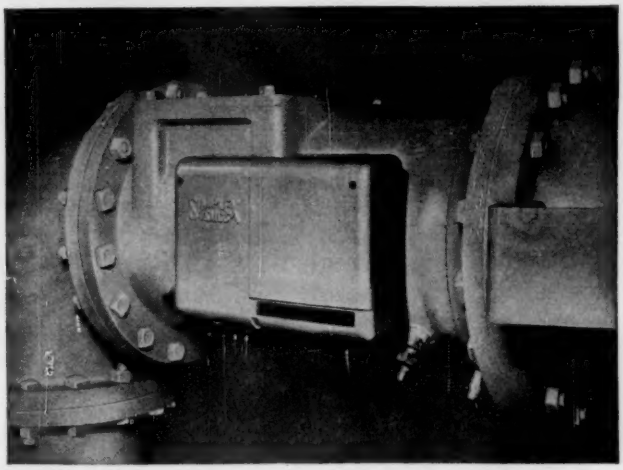
Here's proof that the new Simplex Modulair Controller responds instantly to changes in operating head . . . automatically holds flow at desired rate. Chart from Modulair installation shows head increasing 75% while flow forms almost perfect circle.



How Modulair works! Pipe-like casting with annular Venturi throat houses streamlined inner body with corded-rubber modulator (black) that expands and contracts pneumatically to control flow. When operating head rises, modulator expands automatically to restrict flow to set rate.



When operating head falls, flow tends to decrease—changing the Venturi differential. Sensitive Modulair compensates immediately. Modulator contracts—automatically keeps flow at rate desired.



Compact . . . easily installed Modulair is only 2 to 3 pipe diameters long! Fits wherever a piece of pipe can fit . . . in any position, horizontal or vertical—simplifying piping layout. Modulair comes in 4" to 24" cast iron pipe sizes with corrosion-resisting fittings. Corded-rubber throttling element that's as tough as a truck tire has given 30 years' wear in accelerated life-tests.

Accuracy! In 4 years of field performance, Modulair shows an accuracy in control that exceeds today's most exacting demands. It brings you sensitive, accurate flow control under wide ranges of operating head. And is tight-closing—eliminating need for separate shut-off valves.

Minimize maintenance! With Modulair's single tap design, there's no place for air to accumulate . . . no place for sediment or sludge to lodge and interfere with accuracy. The only moving part inside pipeline is non-corrosive rubber throttling element. Pneumatic poise element is simple, rugged. There are no line valves, no pilot valves, no pistons, no valve shafts, no stuffing boxes to pack!

Lower first cost. Modulair's low head loss means lower operating-head requirements . . . permits vertical compression in plant design and lower costs in plant construction.

Completely pneumatic! No intermediate hydraulic steps! No pilot valves! No hydraulic cylinders! Air loading pressure is applied *directly* to the flow controlling element.

Automatic operation! Modulair works with control systems of any type to give you remote rate control or master pneumatic control that's fully automatic.

Technical bulletin! Write for Bulletin 950. Simplex Valve & Meter Company, Dept. SI-12, 7 East Orange Street, Lancaster, Pa.

Accurate instruments and controls for over 50 years

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Association	*Place*	*Time*
New York Sewage and Industrial Wastes Assn.	Hotel Belmont-Plaza New York, N. Y.	Jan. 17–18, 1957
Texas Water and Sewage Works Assn.	Texas A & M College College Station, Tex.	Mar. 3–8, 1957
New Jersey Sewage and Industrial Wastes Assn.	Traymore Hotel Atlantic City, N. J.	Mar. 13–15, 1957
Arkansas Water & Sewage Conf.	Marion Hotel Little Rock, Ark.	Mar. 18–20, 1957
Louisiana Conference on Water Supply and Sewerage	Univ. of Louisiana Baton Rouge, La.	Mar. 20–22, 1957
Arizona Sewage and Water Works Assn.	Maricopa Inn Mesa, Ariz.	Apr. 4–6, 1957
Kansas Sewage and Industrial Wastes Assn.	Broadview Hotel Wichita, Kans.	Apr. 10–12, 1957
California Sewage and Industrial Wastes Assn.	San Diego, Calif.	May 1–4, 1957
Maryland-Delaware Water and Sewage Assn.	Commander Hotel Ocean City, Md.	May 22–24, 1957
Institute of Sewage Purification	Margate, England	June 17–21, 1957

THIRTIETH ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
New England Sewage and Industrial Wastes Association
Statler Hotel, Boston, Massachusetts
October 7–10, 1957

The percentages are right with

INFILCO *High-Rate* SEWAGE TREATMENT

100%.. ..Faster
50%.. ..Less Space
90-95%.. ..B.O.D. Removal

INFILCO'S improved activated-sludge equipment for *high-rate* sewage treatment is the answer to problems of maximum volume from minimum space—highest efficiency at lowest cost.

Complete treatment requires only five to six hours as compared to 10 to 12 hours in conventional plants. Area required is scarcely half as much. Expenses for property, construction, and operation are substantially reduced. And all this without sacrifice in efficiency. Here are typical operating figures from the installation in Collinsville, Okla.—

EFFICIENCY

Date	Ave. Flow MGD	Average B.O.D. Raw Sewage	Average B.O.D. Final Effluent	Average B.O.D. % Removal	Suspended Solids Raw Sewage	Suspended Solids Final Effluent	Suspended Solids % Removal
1/14-2/3, '55	.069	287	21	92.7	335	22	96.5

These figures indicate what can be accomplished in treatment of sewage for institutions or small communities. If you have such a problem, consult INFILCO, because

INFILCO KNOWS HOW to help you solve it.

Over 60 years of experience and the most complete and advanced line of equipment are available to you. Write today for full information on the interesting Collinsville installation and Bulletin No. 6550.—SI-26.

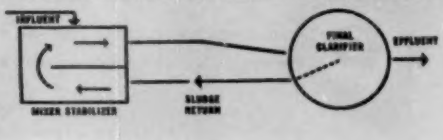
Inquiries are also invited on all other water and waste treating problems including coagulation, precipitation, sedimentation, filtration, flotation, aeration, ion exchange and biological processes.

BIOSORPTION® activated-sludge plant for treatment of sewage at Collinsville, Okla.

Consulting Engineers: **WOOD & CRAIG** *Tulsa, Okla.*

COLAFLEX® diffusers

FLOW DIAGRAM: DESIGN AVERAGE FLOW 0.21 M.G.D.



48 COLAFLEX® diffusers in mixer-stabilizer

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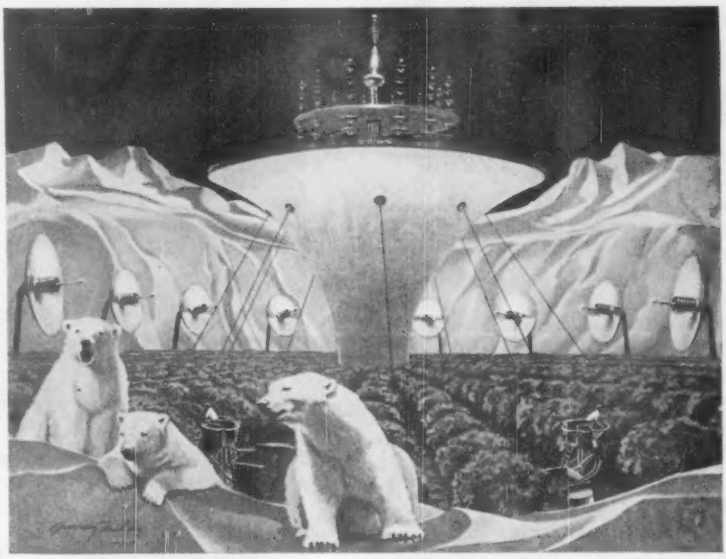

Huge solar engines imprisoning the heat of the sun may create islands of fertility in icy wastelands, thus vastly increasing the productive food areas of the earth.

100 years from now...

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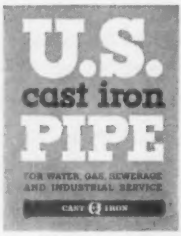
What will the world be like generations from now? Wonderful new products and methods will make living easier, pleasanter, safer. But in this marvelous new era, one old friend will still serve efficiently. Water and gas will be carried by rugged cast iron pipe laid today. For more than seventy American water and gas utilities, cast iron mains over a century old are still serving dependably. And modern cast iron pipe ...centrifugally cast and quality controlled...is far tougher and more durable.

U.S. Pipe is proud to be one of the leaders in a forward-looking industry whose service to the world is measured in centuries.



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A WHOLLY INTEGRATED PRODUCER FROM MINES AND BLAST FURNACES TO FINISHED PIPE.

Sure way to clarify industrial wastes

from this to this

Glass graduate at left shows waste as it flows into settling tank at chemical plant. Mound of sludge filter cake in center represents solids taken from liquid (right) before discharge into sewerage system.

LINK-BELT Circuline Collector concentrates sludge fast in treating corrosive waste at Ohio chemical plant

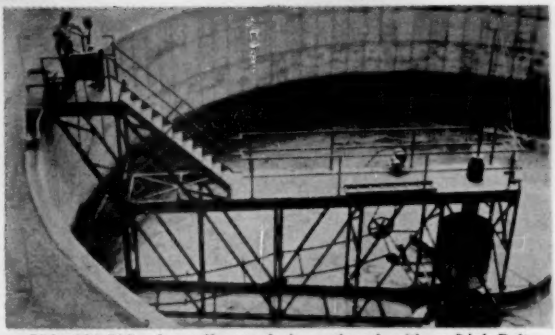
In Cincinnati, surcharges are levied on industrial wastes that exceed maximum legal strength when discharged to city sewers. At the St. Bernard, Ohio plant of Toms River-Cincinnati Chemical Corporation, Cincinnati Division, corrosive and abrasive acid wastes make treatment prior to discharge to the city sewerage system the most economical disposal method.

As in municipal water and sewage plants and industries throughout the country, Link-Belt had a hand in the solution. A Circuline Collector in the settling tank gathers settled sludge so gently that minimum agitation and maximum concentration occurs. This results in high tank efficiency in removing solids and minimum costs to dewater the sludge. It is meaningful that in seeking maximum efficiency and maximum sludge density, Link-Belt equipment was recommended by the consultants, R. L. Woolpert Co. of Dayton.

In the same way, our engineers will help work out answers to your specific needs, collaborating with your engineers, consultants and chemists. Call the Link-Belt office nearest you.

LINK-BELT

SANITARY ENGINEERING EQUIPMENT



This 200,000-gal. settling tank is equipped with a Link-Belt Circuline Collector using Link-Belt Promal chain. Power is supplied through a Link-Belt worm gear and roller chain drive.

After sludge is concentrated in two 13,500-gal. tanks, it is dewatered on a coil-spring vacuum filter and carried from filter by Link-Belt 18-in. wide belt conveyor to be trucked to a dump.

LINK-BELT COMPANY: Executive Offices, Prudential Plaza, Chicago 1. To Serve Industry There Are Link-Belt Plants and Sales Offices in All Principal Cities. Export Office, New York 7; Canada, Scarboro (Toronto 13); Australia, Marrickville, N.S.W.; South Africa, Springs. Representatives Throughout the World.

13,971

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hands, too)

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This rugged old cast iron water main, still serving and saving tax dollars for the citizens of *Detroit, Michigan*, is now in its 115th year of dependable service.

CAST IRON PIPE. Serves for Centuries!

For over 70 public utilities in the United States and Canada, cast iron mains laid over a century ago are still serving dependably. This long, trouble-free service means lower maintenance costs . . . fewer tax dollars expended . . . fewer headaches for the waterworks officials who specify cast iron.

And today, modernized cast iron pipe, centrifugally cast, is even more rugged, uniform, durable. When needed, it's available with cement-lining to assure sustained carrying capacity throughout its generations of service.

The next time you plan extensions to your distribution system remember, cast iron pipe means the ultimate in long term reliability and economy.

Cast Iron Pipe Research Association, Thos. F. Wolfe, Managing Director, 122 So. Michigan Ave., Chicago 3, Illinois.

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The Q-Check stenciled on pipe is the Registered Service Mark of the Cast Iron Pipe Research Association.

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for your plant!

Eight aeration tanks at Lima, Ohio, rehabilitated with DIFFUSAIR equipment. Operating results show improved B.O.D. reduction and air utilization.

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Chas. H. Shook, Inc., Dayton, O., Gen. Cont'r.
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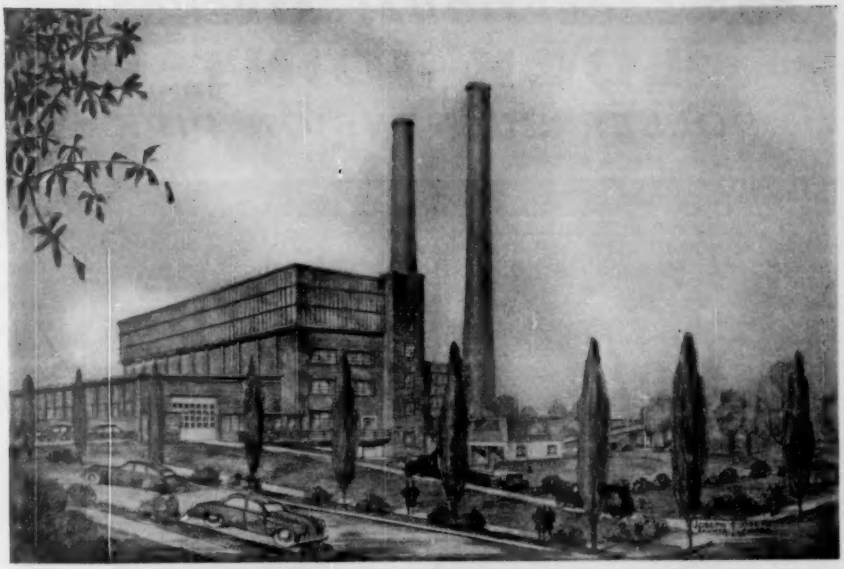
DIFFUSAIR

Walker Process DIFFUSAIR aeration units eliminate many of the difficulties usually associated with the operation of aeration equipment. The short tube orifices of the DIFFUSAIR spargers are designed so that the high velocity of air acts to keep the unit clean. This simple and effective action eliminates the need for air filters resulting in a substantial saving in equipment costs. Further savings are realized due to the virtual elimination of maintenance on DIFFUSAIR units. The self-cleaning spargers require no attention. Also, there is absolutely no back pressure build-up to hamper blower efficiency permitting full air utilization. At Lima, Ohio, old equipment required 1.0 to 2.0 cu. ft. of air per gallon of sewage treated. The installation of DIFFUSAIR equipment has averaged only 0.7 cu. ft. of air and B.O.D. reduction has been raised to 92%-94%.

A Bulletin 22S61, explaining complete details of DIFFUSAIR equipment is available upon request. Write for your copy today!

WALKER PROCESS EQUIPMENT INC.
Factory—Engineering Offices—Laboratories
Aurora, Illinois



Architect's drawing of the Louisville, Kentucky refuse incineration plant—Joseph and Joseph, Architects.
Not illustrated is the new Sewage Treatment Plant, Metcalf and Eddy, Engineers.

LOUISVILLE USES REFUSE TO DISPOSE OF SEWAGE SLUDGE

The City of Louisville, Kentucky is currently building a new sewage treatment plant and—several miles away—a new refuse incinerator plant.

Rather than incorporate sludge disposal facilities in the new treatment plant, the City will truck filter cake to the refuse incinerators. There, two C-E Raymond Flash Drying Systems will utilize the waste heat from the incinerators to dry the filter cake for use as a fertilizer or prepare it for burning in the incinerator with the refuse. For Louisville, this combination of facilities offers a number of advantages. Among them are—

Least First Cost for a system capable of drying, incinerating and deodorizing. The refuse incinerator eliminates the need of a separate drying furnace.

Least Operating Cost because it taps a source of "no cost" BTU's, thereby eliminating the need of purchased fuel.

Maximum Flexibility since the City can dry any amount of sludge for sale as a fertilizer or for use on municipal golf courses, parks and lawns. Any unused sludge can be incinerated with the City's refuse.

If you are considering new sewage disposal facilities—alone or in combination with refuse disposal, see C-E. We will be happy to discuss your needs with you and with your consultants. No obligation of course. Remember, *more filter cake is dried and/or incinerated by the C-E Raymond System than by all other systems combined.*

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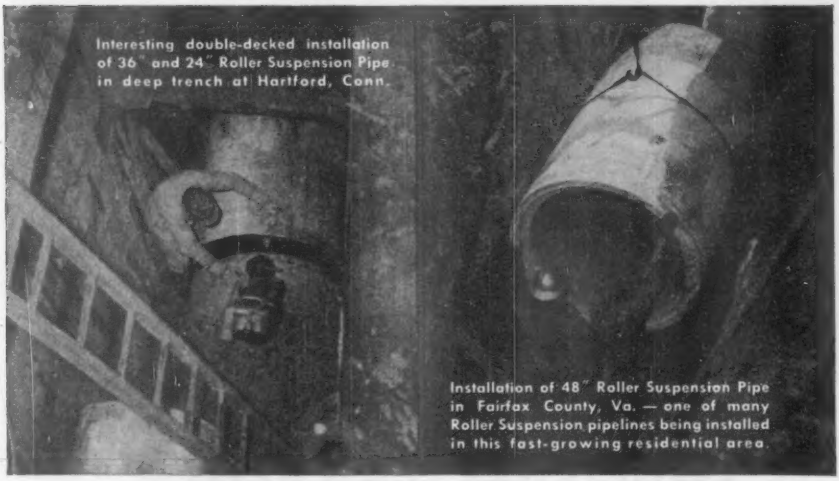
ROLLER SUSPENSION PIPE



Interesting double-decked installation of 36" and 24" Roller Suspension Pipe in deep trench at Hartford, Conn.

Installation of 48" Roller Suspension Pipe in Fairfax County, Va. — one of many Roller Suspension pipelines being installed in this fast-growing residential area.

The unique manufacturing process by which Lock Joint Roller Suspension reinforced concrete sewer and culvert pipe is produced permits the use of a low water-cement ratio and a high proportion of stone in the mix. The concrete obtained by this system is unusually strong and resistant to abrasion.

Roller Suspension Pipe of equal wall thickness and steel area to cast or machine made concrete pipe consequently offers a considerable premium in strength and durability. For projects requiring exceptionally rugged sewer or culvert pipe, specify Lock Joint's ultra-modern ROLLER SUSPENSION PIPE.

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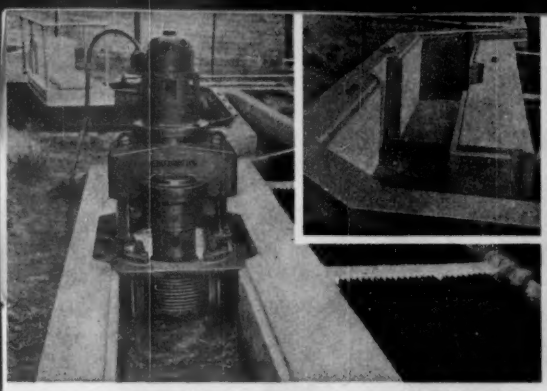
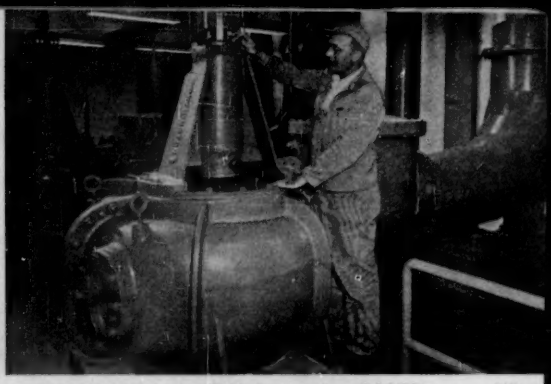
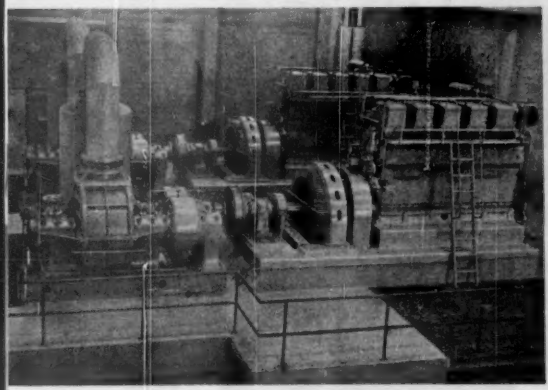
Also Great Lakes Concrete Pipe Company with plants at Buffalo, N. Y. and Henrietta, N. Y.



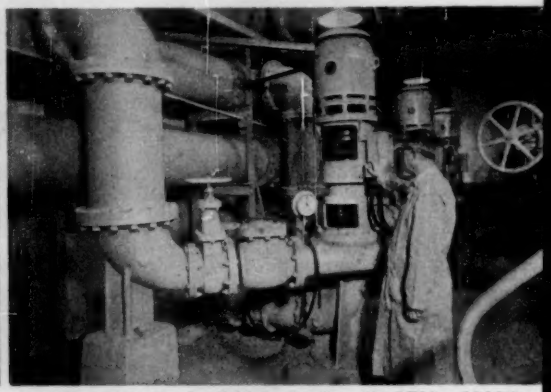
COMMINUTORS. Since raw sewage flows straight through in the Worthington design, the comminutor can be installed in a simple rectangular channel (inset) without expensive masonry work. This one is located at Klamath Falls, Ore.



MIXFLO PUMPS. Available in sizes from 2 MGD to over 300 MGD, Mixflo pumps have non-clogging sewage-type impellers for passing large solids. This one handles raw sewage in the new Salem, Ore., Treatment Plant.



DUAL-FUEL ENGINES. Operating on oil or gas or any combination of both, these Worthington dual-fuel engines drive blowers for the Little Ferry, N. J., Treatment Plant of Bergen County Sewer Authority.



FREFLO PUMPS. Available in sizes from 100 GPM to 5 MGD, these Worthington Freflo pumps in the Bethlehem, Pa., Sewage Disposal Plant offer maximum freedom from clogging.

How to get more for your equipment dollar

Be sure you take advantage of the extra services offered to municipalities considering sewage treatment plants. Regardless of the size of the installation you plan, whether large or small, here's how Worthington can help you.

Trained specialists will sit down with you and study the situation in the planning stage. They will help you recommend, step-by-step, the best and most up-to-date equipment to do your specific job in the most economic way.

An unbiased recommendation. Because Worthington makes a complete line of engines, compressors, comminutors, pumps, and auxiliary equipment, you get an equipment recommendation based on a broad look at *all* available ways of doing the job.

Unit responsibility. You do business with one company—eliminating delays and inconvenience that can occur when you are forced to co-ordinate the efforts of several suppliers.

Some of the sewage treatment plant equipment built by Worthington include: pumps; gas, dual-fuel, and diesel engines; vacuum pumps; air and gas compressors, and comminutors.

For more information about any of these products, call your nearest Worthington District Office, or write to Section W65, Worthington Corp., Harrison, N. J. In Canada: Worthington (Canada) 1955, Ltd., Toronto, Ont.

W-6.5R

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CHAPMAN
MOTOR UNITS
...for Valves, Floorstands, and Sluice Gates

It's a matter of simple mathematics. Take any one of Chapman's Motor Units and look it over carefully. You'll find approximately half as many parts as with any other make. This means the chances of cutting maintenance costs are two to one in your favor.

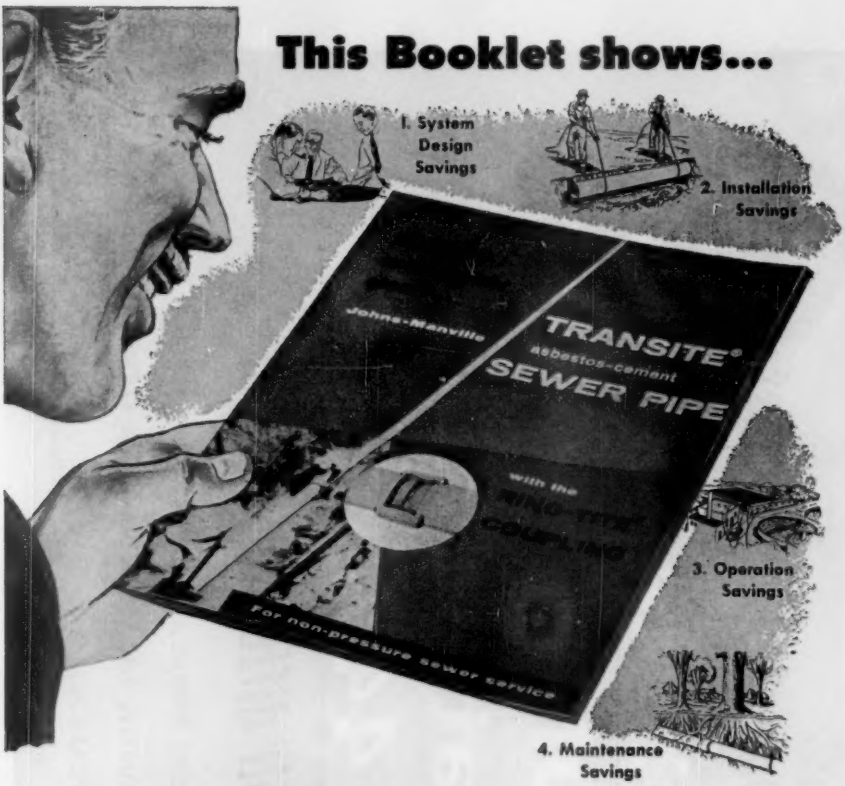
The odds can be even better. With Chapman Motor Units, you not only get simplified design, you also get sturdy construction and smooth, accurate performance over a longer period of time. There's no drift. Backlash is low. An accurate micrometer-controlled limit switch keeps seat tightness at any predetermined level.

Two points more — with Chapman Motor Units there's no trouble with either operating positions or operating conditions. Rugged stub-tooth gears require no grease or oil . . . operate at any angle . . . and the complete unit is not only weatherproof. It's *steam tight.*

Even on installation there's a chance of saving money with Chapman Motor Units. When used with floorstands they are completely wired at the factory . . . ready to connect and work. It's an easy, simple, low-cost job.

Chapman Motor Units for valves, floorstands, and sluice gates are outlined in full in our Catalog 51. If you don't have it, write for it, right now.

The CHAPMAN Valve Mfg. Company
INDIAN ORCHARD, MASSACHUSETTS



...how Transite Sewer Pipe saves in **4** important ways

Selecting the right pipe material for a new sewage system—or for additions to an existing one—is a problem of major importance to *all* concerned in influencing a choice. *And* it can be solved to *the complete satisfaction of both installer and user* with economies in each of these stages—(1) system design (2) installation (3) operation and (4) maintenance.

Engineers thinking in long-range terms of thoroughly proved sewer main performance . . . contractors interested in serving community needs at new lows in installed cost—both should know Transite® asbestos-cement Pipe and Ring-Tite® Coupling. Here is a new booklet that tells how Transite Pipe reduces infiltration, keeps out roots; maintains high flow capacity; speeds installation; permits designing the system for savings. Write for Booklet TR-165A, Johns-Manville, Box 14, New York 16, N. Y.; In Canada, Port Credit, Ont.

Johns-Manville TRANSITE SEWER PIPE

WITH THE **RING-TITE** COUPLING

...for treating domestic and industrial wastes

18-month test shows
HI-CONE system
operating costs
are 44% less!

than air diffusion system

• TESTS PROVE LOWER POWER COSTS!
• LOWER MAINTENANCE COSTS!
• BETTER EFFLUENT

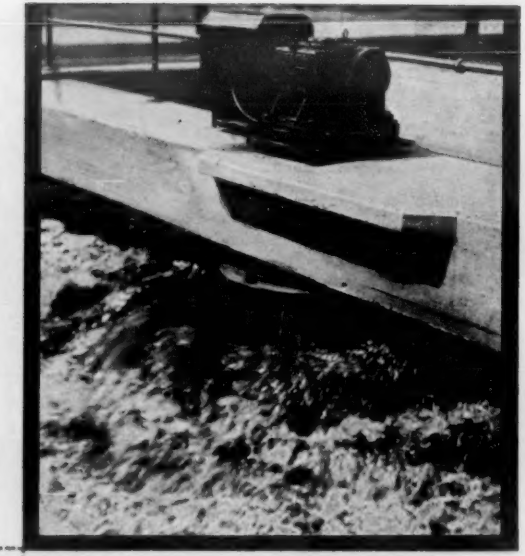
In the selection of sewage treatment equipment, the two most important factors are operating cost and effluent quality.

These figures from the annual report of the Manchester, England, Rivers Department, *prove* the superiority of the Hi-Cone! They're based on the operation of activated sludge plants (including a Hi-Cone System and a diffused air system) under strictly comparable conditions over a period of 18 months. Manchester is a pioneer in treatment by the activated sludge process, having first conducted experiments and tests in 1913.

Hi-Cone's power consumption was lower! Horsepower demand per million gallons treated per 24-hour day for the Hi-Cone System was 34.9% lower than the air diffusion system.

Hi-Cone's total operating costs were lower! Relative costs per million gallons treated were 42.1% lower than the air diffusion system.

Hi-Cone's effluent was better! The B.O.D. reduction was 26% greater; the suspended solids removal was 5% greater than the air diffusion system.



Use this coupon to ask for detailed information

Please send the following descriptive literature on the Hi-Cone:

☐ Cost and operating reports ☐ Report of article, "U. S. and British engineers agree on the Hi-Cone System"

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. . . manufacturers of:
centrifugal pumps • pneumatic sewage ejectors • distributors • clarifiers • mechanical aerators • digesters

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MULTI-MILLION-DOLLAR MIAMI PLANT

Partial view of new Sewage Treatment Plant, City of Miami, Florida . . . buildings, tanks, equipment . . . protected with Inertol Paints.

On Virginia Key, three miles off the Florida mainland, stands Miami's new $10-million sewage treatment plant, heart of the new $27-million sewerage system. To protect this costly installation against the ravages of corrosion, fumes, condensation, salt air, heat and humidity, rugged Inertol coatings were specified (Consulting Engineers: Metcalf and Eddy, Boston, Massachusetts).

Buildings, the four 105′-diameter digesters, the towering chimney structure and other surfaces are protected economically and efficiently with *Ramuc® Masonry Paint.* Thousands more square feet of area of this 47-MGD plant are guarded with other corrosion-resistant, attractive Inertol coatings.

Buy Inertol paints direct from the manufacturer. Shipment within three days from our plant, or from nearby warehouse stocks. Write for free booklet S-754, "Principal Types of Protective Coatings."

SPECIFICATIONS FOR RAMUC MASONRY PAINT

A chlorinated natural rubber-base paint in color. Flat finish. For exterior above-grade masonry. Unaffected by masonry lime. Highly weather- and fume-resistant. No mottling.

Colors: Color Chart 563.
No. of coats: Two (if semi-gloss finish desired, specify semi-gloss type for top coat).
Coverage: 150-250 sq. ft. per gal. per coat, depending on surface texture.
Approx. mil thickness per coat: 1.5.
Drying Time: 24 hours.
Primer: None. However, to minimize efflorescence, specify one coat of Pluvol* as primer.
Thinners: Inertol Thinner 2000-A for brushing; 2000, for spraying.
Application: Brushing: As furnished. Spraying: First coat must be brushed. For spraying, add sufficient Thinner 2000 (10-15%).

Inertol®

*Registered Trademark. *Write for information on Pluvol, invisible silicone water-repellent.*
A complete line of quality coatings for sewage, industrial wastes and water plants.

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Specify IOWA for every job

Iowa's complete line of valves for treatment plants assures you of efficient operation, low maintenance cost, and replacement parts when needed in years to come.

IOWA CHECK VALVES—Swing gate type for use in either horizontal or vertical pipe lines. Bronze trimmed throughout. Stainless steel hinge pins. Leather or rubber faced gates, or solid bronze, as desired—aluminum gates available for air service.

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CLOW HYDROSTATIC RELIEF VALVES — commonly used in bottom of concrete tanks to prevent ground water from floating the tank. Close-grained cast iron body and lid; lead seat ring and lid ring. Cast iron grate in bottom prevents foreign matter from entering tank.

IOWA PLUG DRAIN VALVES—either rising or non-rising stem type. High strength cast iron bodies; bronze stem, operating nut, disc ring and seat ring; rustproof steel bolts and nuts. Handwheels, extension stems, plain or indicating floor stands if required.

IOWA SLUICE GATES—can be used in lines having both seating and unseating pressures. High strength cast iron, bronze mounted, with solid bronze adjustable wedges. Can be equipped with cylinder or motor unit for automatic operation.

IOWA SHEAR GATES—either all iron or iron, bronze mounted. Gate-seating wedges bolted on, permitting replacement without replacing frame.

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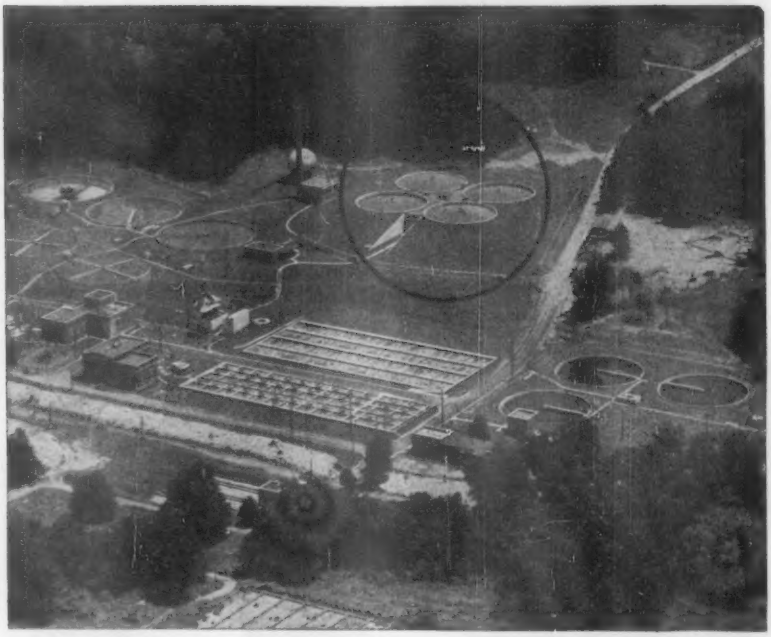

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 28 **December, 1956** **Number 12**

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Ralph E. Fuhrman, *Editor*, 4435 Wisconsin Ave., N.W., Washington 16, D. C.
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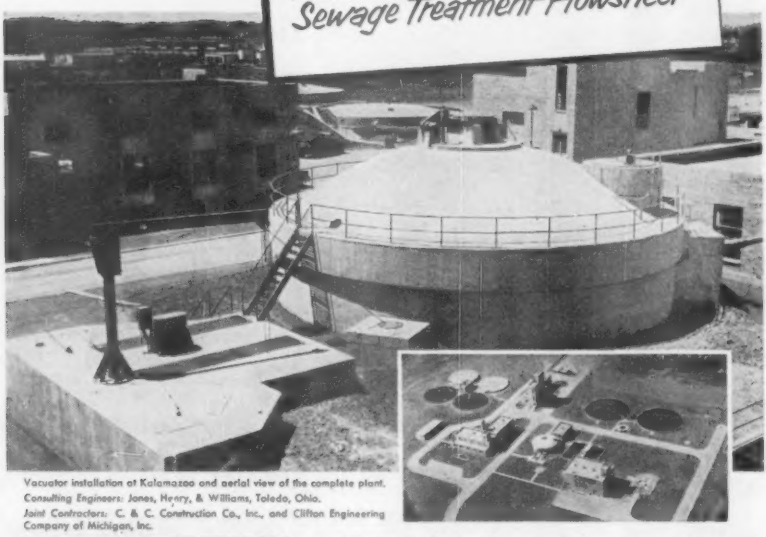
There's a D-O UNIT for Practically Every Step in Every Sewage Treatment Flowsheet



Vacuator installation at Kalamazoo and aerial view of the complete plant.
Consulting Engineers: Jones, Henry, & Williams, Toledo, Ohio.
Joint Contractors: C. & C. Construction Co., Inc., and Clifton Engineering Company of Michigan, Inc.

KALAMAZOO
MICHIGAN
... uses a
DORRCO VACUATOR
for Primary Treatment
... and Chemical
Precipitation to meet
the seasonal fluctuations
of the Kalamazoo River

The 45′ dia. Dorrco Vacuator at the new sewage treatment plant at Kalamazoo is the first major unit of its type in that area. This unique plant flowsheet combines primary treatment with separate sludge digestion . . . with special provisions for chemical precipitation of the Vacuator effluent when a greater degree of treatment is desired.

Other D-O equipment at Kalamazoo includes two Dorrco Flocculator units in basins 54′ x 27′, two 85′ dia. Clarifiers, and two 70′ Dorr Multdigestion Systems.

If you would like more information on the complete line of Dorr-Oliver sewage treatment equipment write to Dorr-Oliver Incorporated, Stamford, Connecticut, for Bulletin No. 6041.

*Flocculator, Vacuator, T. M. Reg. U. S. Patent Off.

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Sewage Works

DEVELOPMENT OF A CONTINUOUS GAS CHROMATOGRAPHIC ANALYZER FOR SLUDGE DIGESTION STUDIES

By Werner N. Grune, James V. Carter, Jr., and J. Peter Keenan

Respectively, Associate Professor, Research Engineer and Research Assistant, Sanitary Engineering Research Laboratory, School of Civil Engineering, Georgia Institute of Technology, Atlanta, Ga.

For a complete investigation of the effects of radioactivity on sludge digestion, both the *quality* and the quantity of the gases of decomposition should be simultaneously observed with respect to time.

The gases produced from digestion undergo qualitative changes with time, as between the important relative amounts to CH_4 and CO_2 produced. This is particularly true during the first phase of batch digestion. Although some research has been performed by others * to study the effect of radioactivity on sludge digestion, it was believed that continuous monitoring and recording of the gas quality from digesters may be an important variable for a more complete evaluation of radiation effects. No changes in gas quality are expected when P^{32} and I^{131} are added to the sludge; however, when C^{14} is applied, the results may be different.

To examine any effect due to radioactive wastes in the sludge, it was considered most expeditious to study the quality of the gas produced from parallel digesters with and without radioactivity. A measurable effect on any of the other variables under investigation, can be readily correlated with the data and examined more closely when a complete qualitative analysis of the gas produced is available. Consequently, the development of a method for the continuous qualitative analysis of sludge gas was undertaken.

During the latter part of 1955 considerable effort went into the development of a method utilizing the principle of thermal conductivity, which has long been a chemical engineer's tool. This approach is especially efficient for gases which differ considerably in thermal conductivity. These gases may be accurately analyzed by a cell which determines the thermal conductivity rate of each gas in comparison with a "standard" gas. It is therefore relatively easy, if certain conditions are met, to analyze a binary mixture of gases. It is also relatively easy to analyze a gas with three components by the simple expedient of using an additional cell. For a complete gas analysis, it would appear theoretically feasible to increase the number of thermal conductivity cells to equal the total number of components in a heterogeneous gas mixture. However, then the circuitry and the apparatus become greatly involved. Moreover, thermal conductivities of the individual components cannot be added together algebraically. This is a distinct limitation inherent in thermal conductivity measurements. Although this was recognized earlier, a

* University of Illinois, sponsored by the United States Atomic Energy Commission.

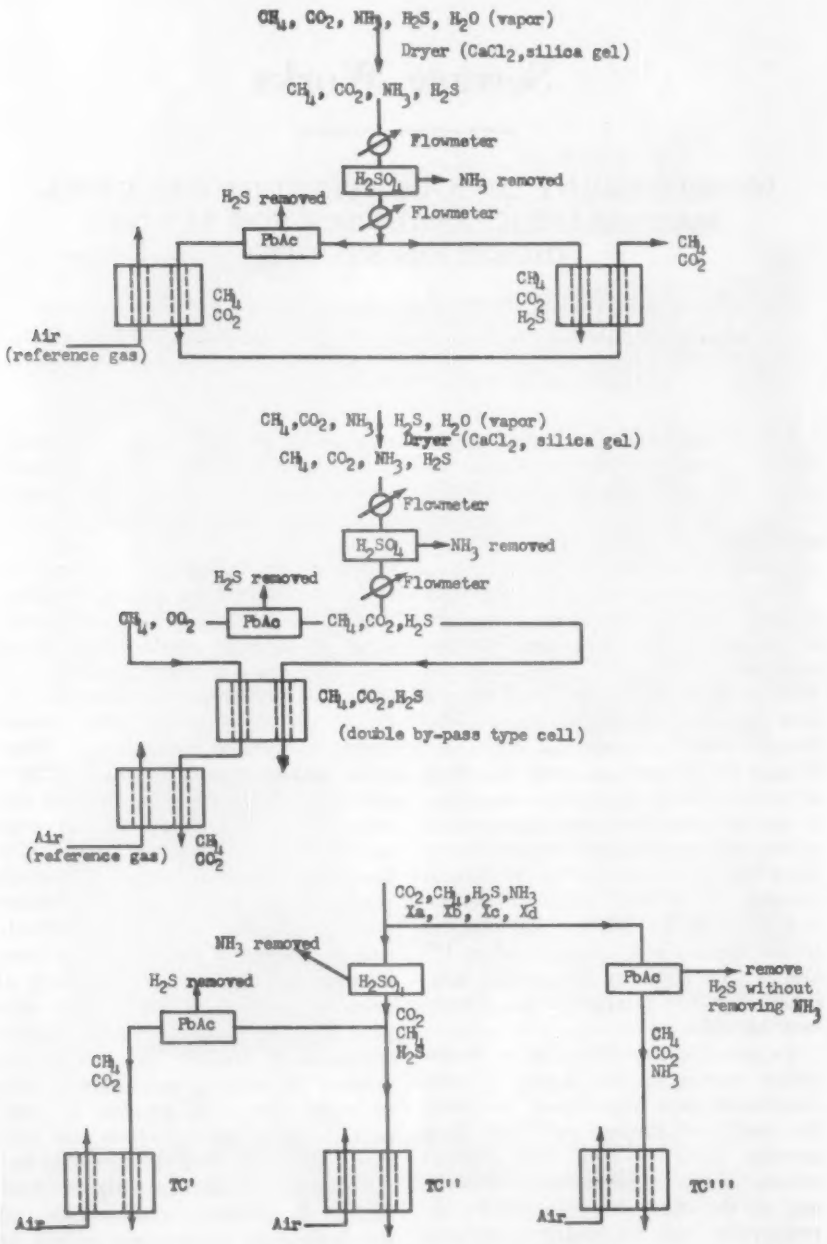

FIGURE 1.—Schematic diagram of thermal conductivity cells for gas analysis. The top diagram shows arrangement of two single by-pass cells. The center diagram shows arrangement of one single cell and one double by-pass cell. The bottom diagram shows arrangement of three single by-pass cells.

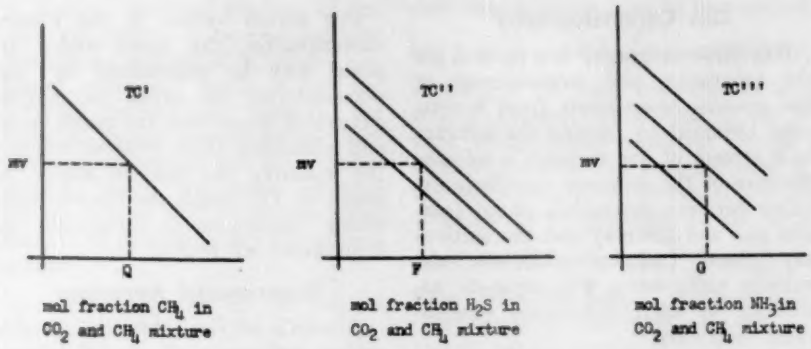

FIGURE 2.—Analytical method for gas analysis using three thermal conductivity cells.

Calculation of Original Gas Compositions

Original gas composition

a = moles of CO_2

b = moles of CH_4

c = moles of H_2S

d = moles of NH_3

X_a = mole fraction CO_2

X_b = mole fraction CH_4

X_c = mole fraction H_2S

X_d = mole fraction NH_3

Reading from *TC'* (Figure 2):

$$Q = \frac{b}{a+b} \tag{1}$$

Reading from *TC''* (Figure 2):

$$F = \frac{c}{a+b+c} \tag{2}$$

Reading from *TC'''* (Figure 2):

$$G = \frac{d}{a+b-d} \tag{3}$$

Then:

$$X_a = \frac{a}{a+b+c+d} \tag{4}$$

$$X_b = \frac{b}{a+b+c+d} \tag{5}$$

$$X_c = \frac{c}{a+b+c+d} \tag{6}$$

$$X_d = \frac{d}{a+b+c+d} \tag{7}$$

$$X_a + X_b + X_c + X_d = 1 \tag{8}$$

$$X_a = \frac{1-Q}{1+\left(\frac{F}{1-F}\right)+\left(\frac{G}{1-G}\right)}$$

$$X_b = \frac{Q}{1+\left(\frac{F}{1-F}\right)+\left(\frac{G}{1-G}\right)}$$

$$X_c = \frac{\frac{F}{1-F}}{1+\left(\frac{F}{1-F}\right)+\left(\frac{G}{1-G}\right)}$$

$$X_d = \frac{\frac{G}{1-G}}{1+\left(\frac{F}{1-F}\right)+\left(\frac{G}{1-G}\right)}$$

method utilizing a series of gas trains with differential gas absorbers was tried (Figures 1 and 2).

The application of all possible inorganic and organic absorbants would not yield a final solution for satisfactory resolution of the various gas components in the heterogeneous mixture. Therefore, in January 1956, the chromatographic method of analysis or vapor fractometry, discarded earlier as too involved, was reappraised. The results from seven months of research into this method and the development of suitable detection equipment for continuous gas quality measurement have proven to be a most fruitful avenue of investigation.

Gas Chromatography

Gas chromatography is a method for the separation and measurement of the gaseous components from a mixture, obtained by passing the mixture in a stream of gas through a column. Because of the different equilibria existing between the mobile phase (carrier gas and sample) and the stationary phase (column material), the various components will separate according to their individual equilibrium constants.

Each component in a mixture may be considered to have its own "affinity" for a given column material. It will therefore cling to that material for a specific time interval which is characteristic to it alone and to no other components. The term "retention time" is used to describe the time during which the component clings to the column before it is driven out by the carrier gas. For a given set of conditions of temperature, flow rate, sample volume, column material, and column size, and with the same carrier gas, the specific component will always have the same retention time. It is this unique "clinging" or retention coefficient for a given column material that differentiates a particular component from all other components.

Gradually, all components will be eluted from the column by the carrier gas. As each component emerges through the column, a thermal conductivity cell measures its concentration. The cell is previously calibrated for each specific component. The graph of the thermal conductivity cell signals shows a series of symmetrical peaks (millivolts as ordinates on a time-axis). The position of the peak along the ordinate and the time-axis is specific for qualitative resolution. It shows the time the component first appears at the detector and how long it took to come out. The area under the peaked curve is a measure of the molar concentration of the particular component in the mixture.

For actual values of the relative concentration, the areas under the peaks may be determined by: (a) planimetering the areas, (b) cutting out actual areas from the graph paper and obtaining their relative weights, (c) counting the squares under the peaks, or (d) using the discriminator which continuously integrates the areas under all peaks.

Experimental Apparatus

A search of the literature revealed several references of special interest (1)(2)(3)(4)(14). One of the most interesting references, because the gases treated are almost identical to the components found in the sludge gas, is the work reported by Ray (5)(6).

Chromatography

The literature distinguishes between two major techniques used in the separation of components in the vapor phase as: (a) partition chromatography (gas-liquid separation) and (b) adsorption chromatography (gas-solid separation). Subdivisions in technique are found principally in the different methods in which components are removed from the column. Some of these methods of interest are:

1. Displacement analysis utilizes a displacing vapor which is more strongly absorbed by the column material than any of the components. The vapor is forced through the column and drives out the various fractions in the order of their increasing affinities for the material.
2. Frontal analysis is similar to displacement analysis except that the mixture itself acts as its own displacement vapor.
3. Temperature gradient analysis consists of moving a heat source along the column to drive out the various components in the order of their respective boiling points. This is the only adsorbent-type column which does not require periodic regeneration.

4. Elution analysis consists of inserting the sample to be analyzed into a continuous stream of a carrier gas (helium, nitrogen) which moves the individual components through the column at speeds depending on their respective retentions by the column material. Each component emerges from the column at the time-rate characteristic of its affinity for the column material.

Careful exploration of all possible techniques has shown that a combination of elution principles with adsorption columns provides the best combination of advantages for the analysis of sludge gas.

It has been considered impossible to obtain continuous separation and analysis of a mixture of gases by gas chromatography due to the nature and mechanism of the apparatus. The only available method has been the infrared gas analyzer (7)(8). Unfortunately this tool is so expensive that it is generally prohibitive both for research and practical application, because a separate gas analyzer is necessary for each gas component. Therefore, an automatically controlled gas sampling valve was developed which continuously samples any number of gas streams programming the feed to the detection device.

Thermal Conductivity

The basic analyzer system consists of a thermal conductivity cell. In all types of thermal conductivity apparatus considered (9)(10), a comparison is made, using some form of the Wheatstone Bridge, between the temperatures of two electrically heated wires, one in the gas to be tested, and the other in a known comparison gas.

The rise in temperature of each wire above that of the surrounding block is, to a first approximation, inversely proportional to the conductivity of the gas. If, therefore, two similar wires, heated by equal currents, are exposed to gases with conductivities K_1 and K_2, their temperatures may be represented by $\theta + \frac{A}{K_1}$ and $\theta + \frac{A}{K_2}$, respectively, where θ is the room temperature and A is a constant. In a form of resistance bridge which measures the difference between the temperatures of the two wires, the deflection of the instrument is proportional to the temperature difference, $A\left(\frac{1}{K_1} - \frac{1}{K_2}\right)$. Thus, when the deflection obtained on comparison of one pair of gases of known conductivities is found, it is easy to calculate the constant of proportionality, A, and to estimate the deflection to be expected from any other pair of gases of known conductivities. Also, in the special case where a variable gas, K_2, is being compared with a constant gas, K_1, the changes in deflection with composition are proportional to the changes in the temperature excess, $\frac{A}{K_2}$.

In the experimental apparatus, the carrier gas may be nitrogen or helium with a constant flow rate through the system maintained by a dual state pressure regulator. The elution gas passes through the reference side of the thermal conductivity cell preceding the point of sample injection. Both elution gas and sample are then carried through the column together. Prior to the injection of the sample, the millivolt meter or recorder must be balanced since both sides of the thermal conductivity cell are incorporated into the Wheatstone Bridge circuit (Figure 3). As soon as a difference in thermal conductivity arises between the two sides of the detector, due to the presence of the sample gas, the resulting bridge unbalance provides a measurable voltage. This signal may then be recorded on a strip chart recorder. Prior to ejection from the column the gas and sample pass through a flowmeter which indicates the quantity and constancy of the flow throughout the system. A tempera-

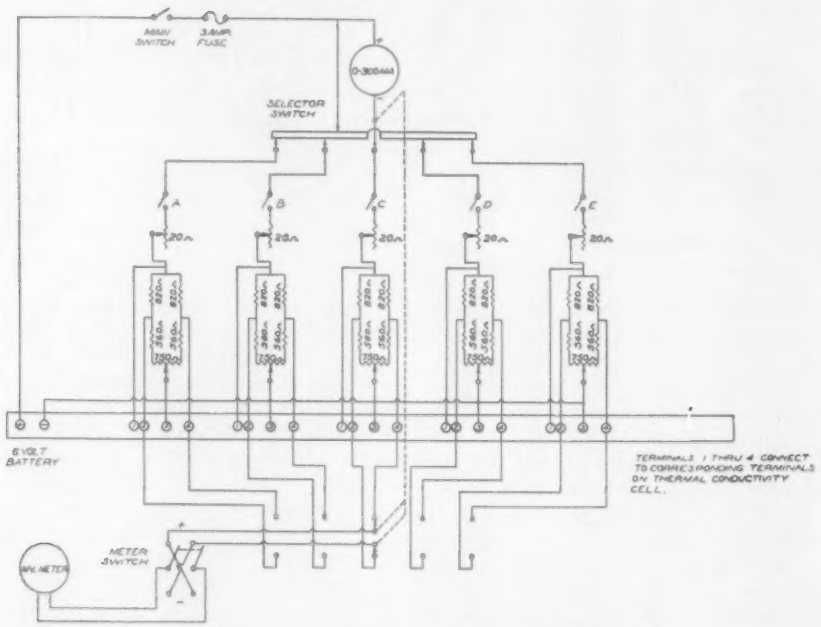

FIGURE 3.—Electrical circuits for thermal conductivity detector.

ture control for the entire system is provided. A schematic diagram of the analyzer is shown in Figure 4.

Progress was slow until the original columns of ⅝-in. O. D. Pyrex heavy-wall tubing, 8 ft. in length, were changed to 5-mm. I. D. tubing, 40 cm. in length, in accordance with the findings reported by Ray (6).

The method of introducing the sample into the system was found to be of considerable importance. To obtain reproducible results the gas sample must be injected at the top of the column as a pure, concentrated sample, thereby eliminating, among other things, poor separations of the constituents in the gas. Furthermore, to place a reproducible sample quantity into the system, the use of meteorological, rubber gas bags was discontinued and a hypodermic syringe substituted. By means of the syringe needle an accurately measured sample of gas is injected through a rubber serum-bottle cap immediately above the top of the column (Figure 5).

One of the most difficult problems to overcome was the large pressure drop in column materials having small voids. For example, a pressure drop of approximately 20 p.s.i. (gage) can be expected with 80-mesh activated charcoal, packed in 8-ft. columns, for each 10 ml. per minute of flow. This is in accordance with the following relationship:

$$\frac{\Delta p}{L} = \frac{5}{g_c} \times \mu \times \frac{36}{D_p^2} \times v \times \frac{(1-\epsilon)^2}{\epsilon^3}$$

where

Δp = pressure drop across column;
L = length of column;
g_c = acceleration due to gravity;
μ = absolute viscosity;
D_p = specific surface diameter of particles in column;
v = rate of flow through empty column; and
ϵ = porosity of column medium.

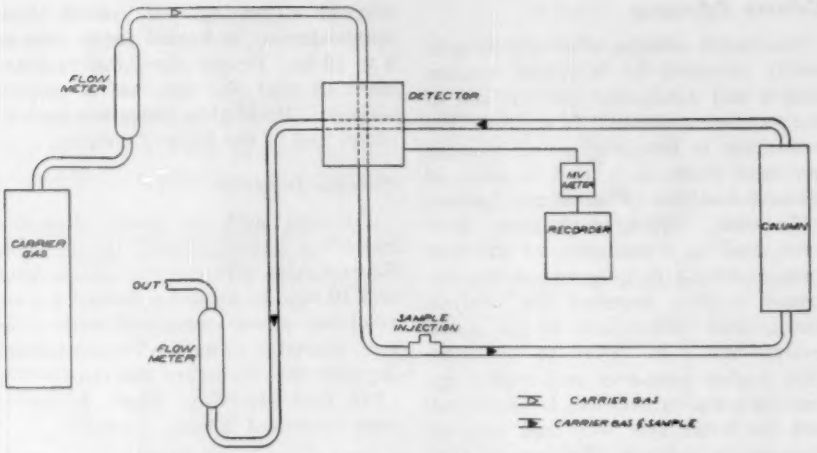

FIGURE 4.—Schematic diagram of chromatographic analyzer.

Within reasonable limits the pressure drop will be increased linearly with increased flow rate. At a flow rate of 50 ml. per minute the source must supply and the system must withstand a pressure of at least 90 p.s.i. (gage). With high flow rates the pressure drop increases somewhat faster than the linear relationship since the viscosity is increasing with increasing pressure. Therefore, at a flow of 100 ml. per minute the pressure increases to approximately 200 p.s.i. (gage) with the 8-ft. activated charcoal column.

Criteria Developed

A considerable amount of research time has been devoted to studies of the many variables, including: flow rate, mesh size of the packing material, method of packing, length of column, diameter of column, means of introducing the gas sample and the sample size. In the course of this work, certain criteria have been developed which may sometimes appear to be contradictory, but should be observed.

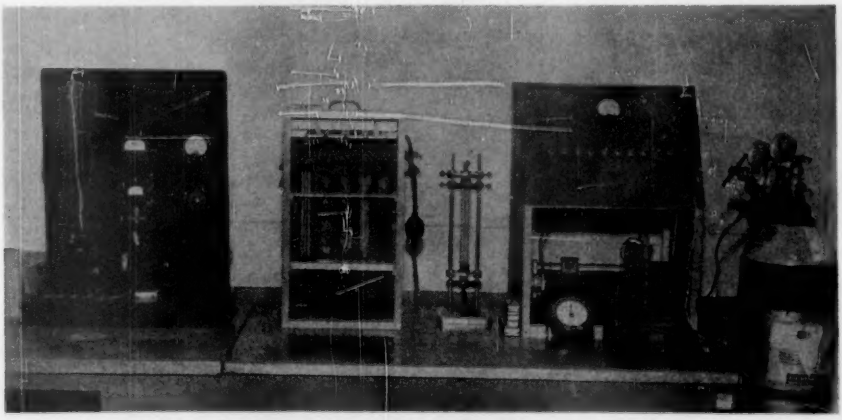

FIGURE 5.—Laboratory apparatus for gas chromatographic analyzer.

Column Efficiency

Increased column efficiency is generally obtained by increased column length and diminished particle size of the support material. It appears that resolution is improved when 80-mesh activated charcoal is used in place of 40-mesh material. Purnell and Spencer (11) state, "These expedients, however, lead to a reduction of the flow rate, resulting in a corresponding increase in time required for analysis and greater 'diffuseness' of the eluted components. In order to overcome this, higher pressures and higher operating temperatures can be employed, but the latter may well lead to a reduction in column efficiency." The efficiency of a gas absorption column is improved by a fast flow rate and an increased size of column (ratio of length to diameter, L/d) and is independent of grain diameter (12). Experience with the work reported herein shows that 80 mesh may be a limiting value with charcoal but that other materials finer than 80 mesh may improve resolution.

Flow Rate

The concentration of the gas is indicated as a function of the peak curve. At low flow rates the curves tend to be wide (with considerable "tailing") and relatively flat with low peaks. With increased flow these curves are compressed, raising the peaks. This shortens the time interval between peaks, or elution of gas components.

Packing Material Size

Resolution increases with a decrease in particle size. However, the elution time is also increased.

Packing Method

All packing materials should be carefully screened and oven-dried prior to use. Activated charcoal is dried at 140° C. for 45 min. Other column materials, such as crushed firebrick, are heated to 120° C. for 30 min. without a coating. If coated these materials may be heated for as long as 8 to 12 hr. Proper care must be exercised so that the material is packed airtight. Spun-glass plugs are used at either end of the finished column.

Column Diameter

Columns with an inside diameter exceeding 5 mm. should not be used. Several runs with columns 25 cm. long and 10 mm. in diameter showed a poor resolving power compared with a 5-mm. diameter column. These findings support the literature references (6) (13) that resolving power decreases with increased column diameter.

Sample Quantity

Peak height varies directly as the quantity of sample introduced. The smaller the quantity used, the narrower the peak and consequently the better the separation. A sample size exceeding 8 to 10 cu. cm. becomes difficult to resolve. The optimum size, considering strength of millivolt signal and resolution, seems to be about 2.0 or 3.0 cu. cm. of sample.

Retention Time

The retention time depends on temperature, rate of flow, sample volume, column material, column size (L/d), carrier gas and pressure.

Degree of Separation

The degree of separation depends primarily on the length of the column provided all other factors are equal.

Tailing Effects

The effect of tailing may be eliminated in several ways. The best approach is to cut the column size (shorter column with smaller diameter to preserve L/d ratio), thereby increasing the flow rate. This will decrease the time of flow for the same sample size, thereby decreasing the tailing effect and improving the resolution. It is also possible to raise the

temperature, thereby decreasing the retention time of each gas according to the equation

$$\tau = \tau_0 \times e^{\frac{H}{RT}}$$

This is of course the perfect gas relationship. An adsorbent of lower activity such as silica gel also may be used. Furthermore, tailing effects may be due to nonuniformity of particle size. The limits of particle size must be carefully adjusted before accurate readings can be obtained and reproducible data achieved.

TABLE I.—Results of Some Continuous Gas Chromatographic Analyses

(A) Activated Charcoal

Column diam.: 5 mm.
Column length: 42 in.
Flow rate: 25 ml./min.
Sample size: 2 to 6 cu. cm.
Coating: None
Date: June 6, 1956

Component Analyzed	Peak Value (mv.)	Elution Time (min.)
CH_4	8.5	22.75
CO_2	4.5	35.00
NH_3	4.0	18.00
N_2	4.3	19.50

(B) Activated Charcoal

Column diam.: 5 mm.
Column length: 25 cm.
Flow rate: 25 ml./min.
Sample size: 2.0 cu. cm.
Coating: None
Date: June 25, 1956

Component Analyzed	Peak Value (mv.)	Elution Time (min.)
Air	5.2	2.5
CH_4	15.8	6.0

(C) C_{22}, J-M Firebrick and Activated Charcoal

Column diam.: 4 mm.
Column length: 4.75 ft. C_{22} and 3.0 in. charcoal
Flow rate: 25 ml./min.
Sample size: 3.0 cu. cm.
Coating: Silicone on C_{22}
Date: July 2, 1956

Component Analyzed	Peak Value (mv.)	Elution Time (min.)
Air	4.2	2.2
CH_4	6.6	3.0
CO_2	4.05	5.0

TABLE I.—*Continued*

(D) C_{22}, J-M Firebrick with and without Activated Charcoal

Column diam.: 4 mm.
Column length: 5 ft.
Flow rate: 30 ml./min.
Sample size: 2.0 cu. cm.
Coating: Silicone on C_{22}
Date: July 5, 1956

Component Analyzed	Length of 80-Mesh Charcoal	Peak Signal (mv.)
CH_4	None	15
CH_4	¼ in.	2.8
CH_4	1.0 in.	1.2
CH_4	2.0 in.	0.2

(E) C_{22}, J-M Firebrick (25 Mesh)

Column diam.: 4 mm.
Column length: 8.75 ft.
Flow rate: 30 ml./min.
Sample size: 2.0 cu. cm.
Coating: TCP*
Date: August 2, 1956

Component Analyzed	Peak Value (mv.)	Elution Time (sec.)
CH_4	0.8	57
CO_2	1.1	85
NH_3	0.4	10

* C_{22} coated with TCP and ¼-in. silica gel at column entrance.

Results

Listed in Table I are some typical examples of results obtained with experimental columns using continuous gas chromatography.

The tabulation in Table I represents only a small portion of the work performed. To date, 28 different columns have been prepared and a complete

evaluation study of their characteristics and practicability is presently being undertaken.

Considerable effort has been expended on the chromatographic method of gas analysis and the results have been increasingly satisfactory. Continued studies will be necessary to determine whether partition or adsorption chromatography will produce the desired results with sewage sludge gas. Present indications are that adsorption chromatography will be most effective.

Acknowledgments

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References

1. Patton, H. W., Lewis, J. S., and Kaye, W. I., "Separation and Analysis of Gases and Volatile Liquids by Gas Chromatography." *Anal. Chem.*, **27**, 170 (Feb., 1955).
2. Hausdorff, H. H., "Vapor Fractometry (Gas Chromatography)." *Anal. Chem.*, **27**, 42a (June, 1955).
3. Patton, H. W., and Lewis, J. S., "Fractionation and Analysis on Micro Scale by Gas Chromatography." Third National Air Pollution Symposium, Los Angeles, Calif. (Apr. 18, 1955).
4. Miller, C. T., "Gas Chromatography: Automatic Analyzer for the Chemist." *Research and Engineering*, **2**, 2, 26 (Feb., 1956).
5. Ray, N. H., "Gas Chromatography. I. The Separation and Estimation of Volatile Organic Compounds by Gas-Liquid Partition Chromatography." *Jour. Appl. Chem.*, **4**, 21 (Jan., 1954).
6. Ray, N. H., "Gas Chromatography. II. The Separation and Analysis of Gas Mixtures by Chromatographic Methods." *Jour. Appl. Chem.*, **4**, 82 (1954).
7. Waters, J. L., and Hartz, N. W., "An Improved Luft-Type Infrared Gas and Liquid Analyzer." Conference of the Instrument Society of America, Houston, Tex. (Sept. 10–14, 1951).
8. "Infra-Red Gas Analyzers." Liston-Becker Instrument Co., Inc., Stamford, Conn.
9. Daynes, H. A., "Gas Analysis by Measurement of Thermal Conductivity." Cambridge University Press (1933).
10. Minter, C. C., and Burdy, L. M., "Thermal Conductivity Bridge for Gas Analysis." Naval Research Laboratory, Washington, D. C.
11. Purnell, J. H., and Spencer, M. S., "Use of Solubilizing Agents in Gas-Phase Partition Chromatography." *Nature*, **4466**, 988 (June 4, 1955).
12. Williams, R. J. P., "Gradient Elution Analysis." *Analyst*, **77**, 915 (Dec., 1952).
13. Phillips, C. S. G., "The Chromatography of Gases and Vapors." *Disc. Faraday Society*, **7**, 241 (July 14, 1949).
14. James, A. T., and Martin, A. J. P., "Gas-Liquid Chromatography." *British Medical Bull.*, **10**, 3, 170 (1954).

RESERVE COMMISSIONS, ARMY MEDICAL SERVICE CORPS

The U. S. Army is offering a limited number of reserve commissions to qualified chemical, civil, and sanitary engineering graduates. Approximately 50 engineers are expected to be commissioned during the next two years in grades from second lieutenant through captain. Appointment will be concurrent with a call to active duty.

Applications will be accepted contingent upon graduation from a recognized university within four months of submitting application. Information may be obtained from any of the Army Area offices or the Department of the Army, Office of the Surgeon General, Technical Liaison Office, Washington 25, D. C.

FUNDAMENTAL OPERATING VARIABLES IN SEWAGE SLUDGE FILTRATION *

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The rotary vacuum filter for sewage sludge dewatering has been a somewhat recent addition to sewage treatment plants compared with many of the other types of mechanical process equipment. However, considerable effort has been directed toward the determination of the optimum operating conditions of the filters by many workers in this field.

In general, the work has been done by investigators at the large municipal treatment plants for the purpose of minimizing operating costs or increasing the capacity of the filtration equipment. Notable contributions have been made by Wilson *et al.* (1) (2), Mohlman and Edwards (3) (4), Genter (5), and others. More recently, extensive studies by Halff (6), and Beck, Sakellariou and Krup (7) have shown the effect of the various operating variables on cake moisture or filtration rate. The majority of these data have been obtained with a Buechner funnel, or using a modified Buechner test technique.

The objectives of the investigation described herein were somewhat different from those in most of the work previously noted. On the basis of a thorough examination of filter operating reports and the literature, it was decided that a combined laboratory and pilot plant study to determine the effects of the principal operating variables on filtration rates and cake moistures was required.

This type of analysis provides the information necessary for proper filter design and for setting the optimum filter station operating conditions at a given plant. Since the two primary considerations in sludge filtration are the dry solids rate and cake moisture, the study was directed toward analysis of the effect of the operating conditions on these variables. Drum submergence, cycle time or drum speed, operating vacuum, sludge concentration, and sludge treatment or composition, were studied.

Test Program

The test program was designed so that the majority of the initial work could be done at one sewage treatment plant in order to have as nearly the same conditions from day to day as possible.

The filter unit was installed at the Michigan State College †—City of East Lansing sewage treatment plant, with several types of sludges available for filtration testing. The filter station consisted of a 4-ft. diameter by 2-ft. wide rotary filter with the necessary appurtenances. A flow sheet of the unit is given in Figure 1, the operating filter is shown in Figure 2. Laboratory facilities of the Department of Civil and Sanitary Engineering, Michigan State College, were utilized.

Since it was desired to control the fundamental investigations as closely as possible, all of the initial tests were made on a given type of sludge in the laboratory, where every variable could be adjusted independently. A filter test leaf was used for the laboratory work instead of a Buechner funnel commonly used by many sewage laboratories. The test leaf was used because it simulates a vacuum filter in opera-

* Presented at 1955 Annual Meeting, Pacific Northwest Sewage and Industrial Wastes Assn.; Victoria, B. C.; Oct. 27–29, 1955.

† Now the Michigan State University.

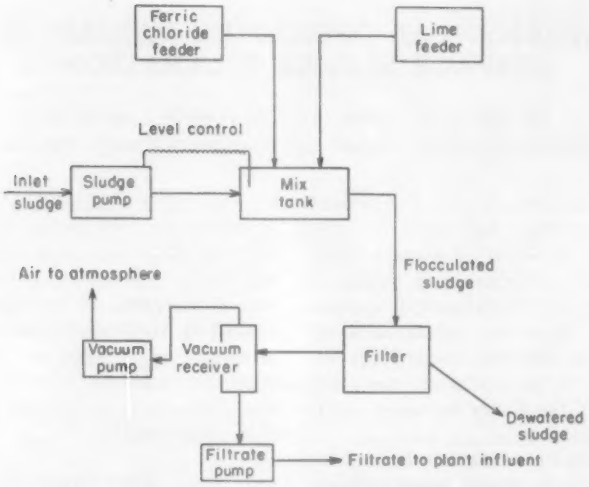

FIGURE 1.—Flow diagram of sludge filter station at East Lansing, Mich., sewage treatment plant.

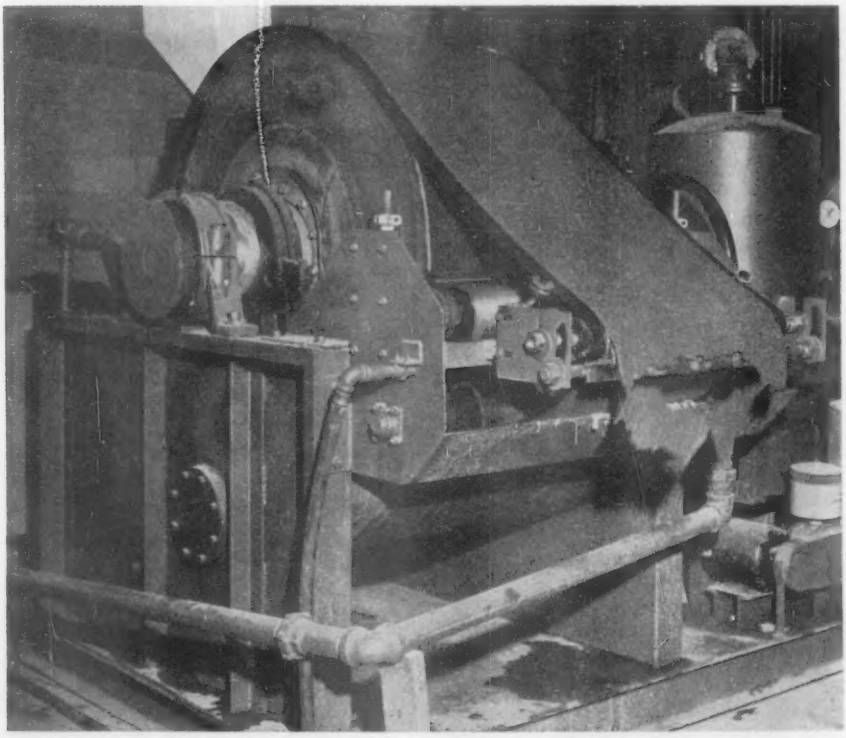

FIGURE 2.—Filter station at East Lansing, Mich., sewage treatment plant.

tion in the pickup, drying and discharging of a filter cake; thus, the results obtained are representative of the operation on a plant-size vacuum filter. The test leaf, a standard Eimco circular leaf with a tapered bottom for drainage, has an area of 0.1 sq. ft. and is fitted to receive a standard ½-in. pipe nipple. The cloth is placed over the face of the leaf and clamped in place with a stainless steel band. The excess cloth is trimmed off and the leaf connected to a filtrate receiver, with the vacuum supplied by a laboratory vacuum pump. The outlet gas from the pump was measured with a bellows-type dry gas meter. This testing apparatus is shown in Figure 3.

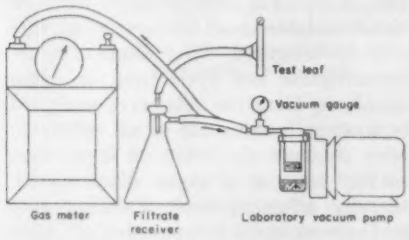

FIGURE 3.—Test leaf apparatus.

A polyethylene cloth was selected for the filter medium because this cloth exhibits good discharging qualities and is easy to clean due to its chemical nature and monofilament structure. The cloth was a 2/2 twill weave with a heat set finish of the most porous weave that produced an acceptable filtrate.

To insure controlled test results, the following test procedure was used. A 4- to 6-gal. sample of representative sludge was stored in a refrigerator maintained at 45° F. A 600-ml. sample was used for each leaf test, with the remaining slurry discarded; that is, no test was performed on sludge which contained any part of the feed from the previous test. The reasons for this procedure are: (a) the ratio of solids to liquid in the remaining slurry will most likely be different from the initial slurry, (b) the distribution of the various sized particles may be different, and (c) the time after the addition of chemicals will be greater.

The last reason is particularly important in that it has been found that optimum filtration occurs as soon as possible after the sludge becomes flocculated. To be sure of maintaining this type of operation, the chemicals were mixed quickly and thoroughly with the sludge to obtain complete flocculation. Upon standing after flocculation, the slurry appeared more difficult to filter and the filtrate rate decreased. Work done by Beck and associates (7) at the Chicago Sanitary District confirms this phenomenon. In these studies, the effect of pH drift (the rise in pH after longer intervals of time between dosing with ferric chloride and actual filtration) upon cake moisture was investigated and found to have no effect. However, it was noticed that actual filtration time on a Buechner funnel increased with increased contact time between sludge and ferric chloride. Thus, increased time between dosing and filtration resulted in lower filtration rates and therefore lower filter capacity.

In all tests the polyethylene cloth was washed immediately after each run to insure a clean cloth surface for each test. The slurries were maintained at 60° F. during the actual tests and the filter cakes were dried at 200° F. for 24 hr. to determine cake moisture content. The conditions were maintained as identical as possible throughout all tests by following this exact procedure.

Effect of Operating Conditions on Filtration Rate

Although cake formation and cake dewatering both occur in essentially one operation on a rotary vacuum filter, they are actually two distinctively different phenomena. There is a definite relationship between the rate of cake formation on the filter and the

rate of cake dewatering; however, from a theoretical standpoint it is necessary to consider these operations separately. This approach also gives a clearer analysis in terms of the measurable filter operating variable, which makes the results easier to apply in designing a sludge filter station and fixing the proper operating conditions.

To make the most effective analysis of the relationships between the filter operating variables and the dry solids rate, the fundamental dynamic filtration expression, shown as a modification of Poiseuille's equation, was considered (8) (9):

$$\frac{dV}{A\,d\theta} = \frac{P}{\mu\left(a\,P\,\frac{Sw\,V}{A} + r\right)} \qquad (1)$$

in which

V = volume of filtrate collected;
θ = time of filtration or form time;
A = filtration area;
μ = filtrate viscosity;
P = pressure drop (or vacuum differential) during cake formation;
S = filter cake compressibility factor;
a = specific cake resistance at P = 1.0;
w = weight of dry cake solids per unit volume of filtrate; and
r = resistance of filter system exclusive of cake (includes filter media, lines, etc.)

By assuming that r is negligible (a valid assumption for these conditions) and that μ and a remain constant as the cake is formed, Eq. 1 can be integrated for constant pressure filtration as follows:

$$\frac{V^2}{A^2} = \frac{2\,P^{1-S}\,\theta}{\mu\,a\,w} \qquad (2)$$

Since W in dry weight of cake = $w\,V$ for each feed solids concentration,

$$\frac{W^2}{A^2} = C\,P^{1-S}\,\theta \qquad (3a)$$

or

$$\frac{W}{A} = (C\,P^{1-S}\,\theta)^{\frac{1}{2}} \qquad (3b)$$

Since Z, in pounds of dry solids per square foot per hour of form time, is expressed as

$$Z = \frac{W}{A} \times \frac{60}{\theta} \qquad (4a)$$

$$Z = (C\,P^{1-S}\,\theta)^{\frac{1}{2}} \times \frac{60}{\theta}$$

$$= \left(K\,\frac{P^{1-S}}{\theta}\right)^{\frac{1}{2}} \qquad (4b)$$

θ, the form time (which is the product of drum submergence and drum speed), and P, the operating vacuum during the cake-forming portion of the filter cycle, are the conditions which are most readily controlled in operating a filter station. Therefore, the theoretical relationships between these variables and the dry solids rate were investigated. The effects of drum submergence and cycle time, or drum speed, on filtration rate were analyzed separately because the drum submergence controls the ratio of form time to dry time at a given drum speed, thereby affecting both filtration rate and cake moisture independently. Also, drum submergence is to some extent fixed by the filter design, whereas drum speed can be varied widely; therefore, an approximate optimum drum submergence must be known before a filter can be constructed and operated in a plant to determine the optimum operating conditions.

Effect of form time or cycle time

Figure 4 shows a plot of filtration rate in pounds of dry solids per hour per square foot of filter area versus cycle time. For a given submergence, in this case 25 per cent, filtration rate (as shown) and cycle time are directly proportional to form rate and form time. The values shown are used because they are the terms normally employed in a plant. The relationship, as indicated by the modified Poiseuille's equation

$$\log R = f\ (\log \theta) \qquad (5)$$

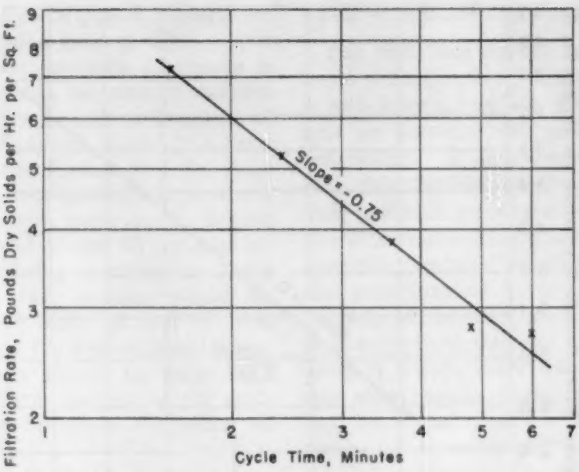

FIGURE 4.—Filtration rate versus cycle time; leaf test data for primary-activated sludge, East Lansing, Mich.; medium, polyethylene 802 HF; vacuum, 20 in. Hg; submergence, 25 per cent.

is shown to be true, but the slope of the curve is -0.75, instead of -0.5 as would be expected for an "ideal" cake. This variance in slope indicates that the cake permeability is changing as additional cake is formed.

The change can be caused by several phenomena, but experience has shown that the usual reason is a migration of fine material in the cake, which causes the reduction in cake permeability. The slope of this curve will vary with different sludges, as shown later by the data obtained with the pilot filter tested at different municipal plants. The slope also may change from day to day, or even from hour to hour, on the same plant sludge, but the results indicate that each specific sludge generally shows a characteristic slope from which the day to day variance is small.

This conclusion is substantiated by the results reported on other materials which show changes in composition from day to day due to various process or feed stock variations. For example, Nickalous and Dahlstrom (10) have published results on the effect of form time on the pressure filtration of brewers' mash, bleached corn oil and yeast; Schepman, Martin, and Dahlstrom (11) have reported their results on this relationship for the filtration of corn gluten. In all of these cases, the filtered slurry composition changed with process alterations, but the relationship between dry solids rate and form time or cycle time remained relatively constant.

With this average plot of filtration rate versus form time, it is possible to separate the effects of cycle time and submergence. By running leaf tests to determine the effect of drying time on cake moisture, the optimum filter submergence and drum speed can be selected.

Effect of Vacuum

From the fundamental filtration equation (Eq. 5), the slope of the curve would be 0.5 for an "ideal," incompressible cake. Figure 5 shows this curve prepared from the leaf test data. It can be seen that the slope is 0.3 instead of 0.5, thereby indicating that the sludge cake is not ideal, but

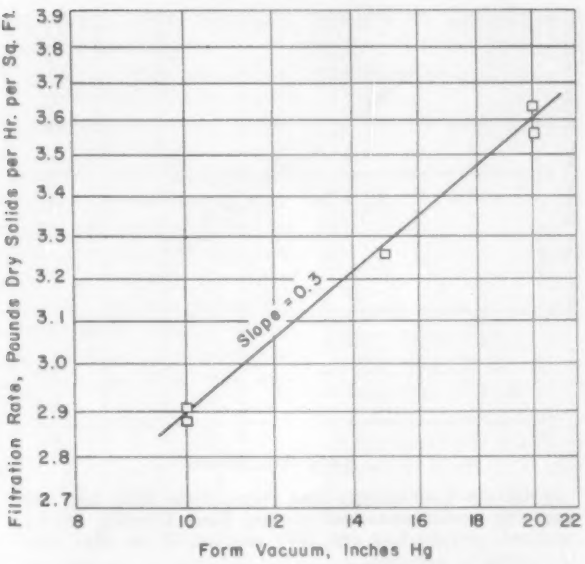

FIGURE 5.—Filtration rate versus form vacuum; leaf test data for primary-activated sludge, East Lansing, Mich.; medium, polyethylene 802 HF; cycle, 3.6 min.; submergence, 25 per cent.

shows definite compressibility. This concept of cake compressibility is not the same as physical compressibility. That is, the fact that moisture can be squeezed out of a cake after it apparently has been dewatered on a filter does not mean that the cake is compressible. Rather, the criterion previously noted is the only basis on which to judge a cake's compressibility. Only if the slope of the curve as shown is less than 0.5 is a cake compressible in this sense.

It might seem that the compressibility exhibited by the primary activated sludge cake would be expected and that other materials with similar characteristics would certainly not form ideal cakes. Such is not the case, however, as the filtration properties of many different materials have been investigated and a very small percentage show compressibility with pressure drops across the cake of one atmosphere or less. For example, proteinaceous materials (such as corn gluten), inorganic chemicals which show extreme compressibility at higher pressures (such as $Al(OH)_3$), and many other organic materials have been investigated, and only a few cakes show this compressibility at low pressure differentials. It would be expected, therefore, that other types of sewage sludge cakes will show less compressibility than activated sludge unless the floccules are extremely small and gelatinous. The test data obtained with the pilot-plant filter on digested elutriated sludge have shown this to be true.

The significance of the relationship between filtration rate and the vacuum during the form portion of the cycle becomes apparent when the effect on actual plant design is shown. It would require 30 per cent more filter area to handle the same quantity of sludge if the filter were operated at a 10-in. vacuum instead of a 25-in. vacuum based on a slope of 0.3 as shown in Figure 5. When it is realized that

essentially no air is pulled through the filter during the form portion of the filter cycle, the economic advantage is apparent, because the cost of vacuum pump capacity is more a function of air rate than vacuum level. If a more ideal cake were formed and the slope of the curve were around 0.5, as would be expected with more easily filtered sludges, instead of only 30 per cent additional area being required (as shown previously), the increase would be nearly 60 per cent. It can be seen, therefore, that the highest possible economic vacuum should be maintained during the form portion of the cycle for the most effective utilization of filter capacity.

Effect of Solids Concentration

The fact that sludge concentration has a definite effect on filtration rate is well known, but it is difficult to obtain an accurate analysis from field test results. It has been shown, however, that the leaf test technique previously outlined gives results representative of actual filter operation. In fact, most filter installations in the chemical and metallurgical fields are sized accurately on the basis of such leaf tests. It is recognized that the effect of sampling is always more difficult to control with sewage sludge than almost any other material due to the wide range of constituents; however, by

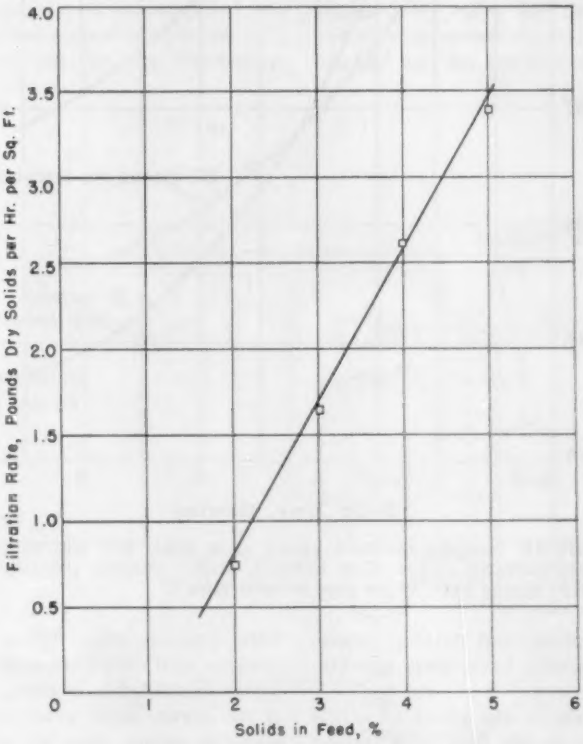

FIGURE 6.—Filtration rate versus solids concentration; leaf test data for primary-activated sludge, East Lansing, Mich.; medium, polyethylene 802 HF; vacuum, 20 in. Hg; cycle, 3.6 min.; submergence, 25 per cent; chemicals, 2½ per cent $FeCl_3$ and 10 per cent lime.

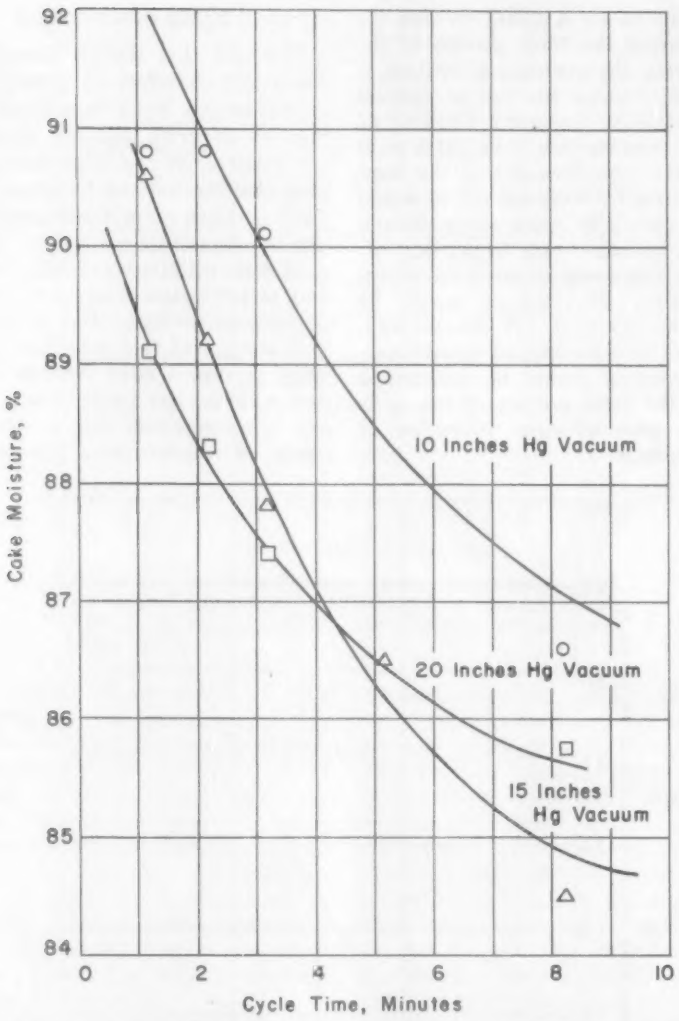

FIGURE 7.—Cake moisture versus cycle time; leaf test data for primary-activated sludge, East Lansing, Mich.; medium, polyethylene 802 HF; drying time, 50 per cent of cycle time.

careful sampling and mixing procedures the results have been satisfactory.

Figure 6 shows the effect of solids concentration in the feed on filtration rate for the leaf test runs. It is evident that the curve is linear and that for this type of sludge the slope of the line is fairly steep. Tests also have been run on other types of sewage sludges and, even though the same linear relationship is noted, the slopes of the curves have varied widely. The absolute values also are different in that primary, primary digested, and other more easily filtered sludges yield considerably higher filtration rates. It definitely can be concluded, however,

that for all types of sludges an increase in sludge concentration will decrease the filter area that is required and reduce the investment for a given filter station.

Effect of Operating Conditions on Cake Moisture

Considerable work has been done by a number of investigators (12) on the theoretical considerations of filter cake dewatering. Most of the work, however, has been done on cakes composed of crystalline, granular, or more free-filtering materials as the effects of particle shape, porosity, and other variables are easier to measure and analyze. Silverblatt and Dahlstrom (13) have developed an empirical factor which gives a good correlation with moisture content for the dewatering of fine coal cakes. This factor is:

$$\left(\frac{\text{CFM}}{\text{Sq. ft.}}\right)(\theta')\left(\frac{P}{d}\right)\left(\frac{1}{\mu}\right) \qquad (6)$$

in which

$\frac{\text{CFM}}{\text{Sq. ft.}}$ = standard (32° F., 1 atm.) volume of air, in cubic feet, drawn through 1 sq. ft. of cake per minute;
θ' = drying time in minutes;
P = vacuum of drying zone;
d = cake thickness; and
μ = filtrate viscosity.

It is evident that the factor includes all of the fundamental variables which would affect the dewatering of sewage sludge filter cake, but these data did not yield a reasonable correlation when applied against the factor. This lack

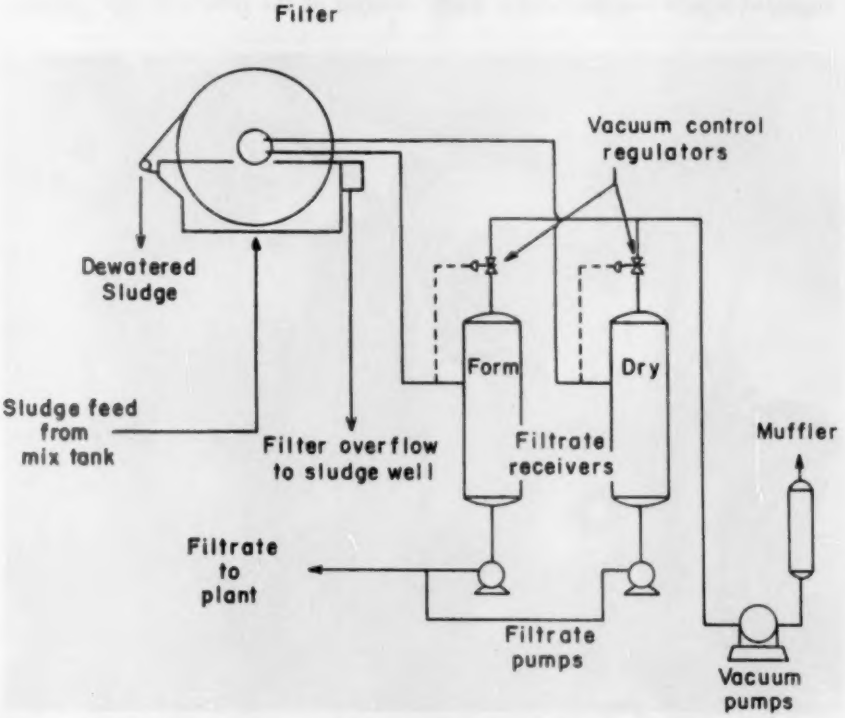

FIGURE 8.—Piping layout for filter vacuum system with vacuum filtration.

of correlation was expected, however, due to the non-porous nature of the sludge cake. It was decided, therefore, to analyze the data in terms of drying time and drying vacuum, the two operating conditions over which the most control can be exercised. Cake thickness also can be controlled, but in considering the optimum operation as a balance between dry solids rate and cake moisture, the cake thickness will not be considered as such.

Figure 7 shows cake moisture as a function of cycle time with parameters of drying vacuum. The expected reduction in cake moisture with longer drying time was obtained, but the curves at 15-in. and 20-in. Hg vacuum intersected at about 2-min. drying time. This intersection occurred because of cracking in the cake when operating at the higher vacuum (20-in. Hg). At 15-in. Hg, however, the cake appeared to have less tendency to crack and dewatered to a lower final cake moisture content. This condition cannot be considered typical, as sludge characteristics will change the specific cake moisture values; but it is significant that minimum cake moistures can be obtained by operating at the highest drying vacuum which does not cause severe cake cracking.

Another innovation, recommended for installations where cake cracking is expected, is to use two vacuum receivers and filtrate pumps, one set for the "form vacuum" connection to the filter and the other for the "dry vacuum" connection. The cost of this additional equipment is not excessive because the form vacuum receiver and the filtrate pump can be small, as only a little air or filtrate is drawn through the filter during this portion of the filter cycle. However, this arrangement does provide positive separate control of the form and dry vacuums

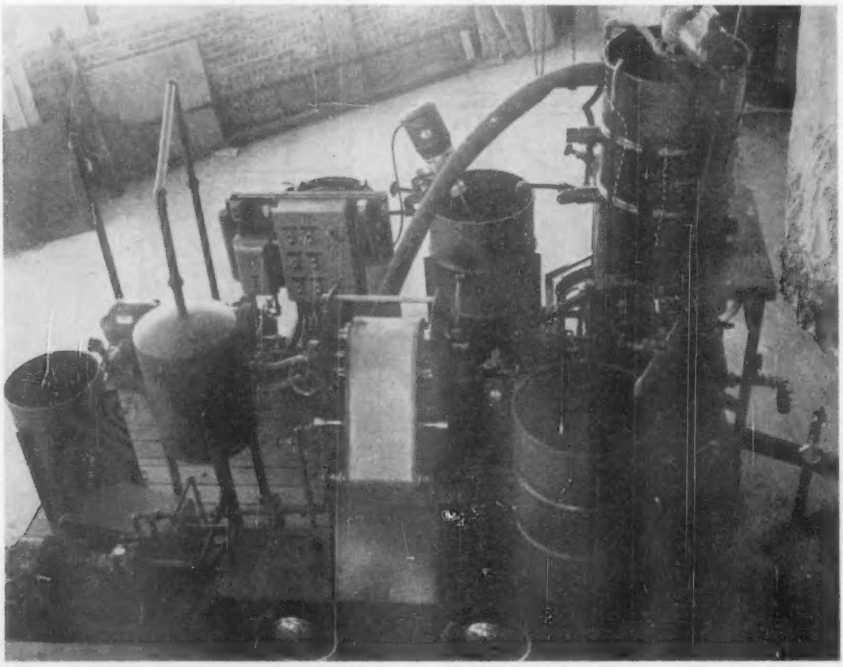

FIGURE 9.—Pilot-plant trailer test unit.

TABLE I.—Comparison of Slopes of Characteristic Curves, Filtration Rates, and Cake Moistures for Different Types of Sludges

Plant	Slope of Curve	Sludge Conc. (%)	Chemicals (%)		Filter Rate (lb./hr./sq. ft.)	Cake Moisture (%)
			CaO	$FeCl_3$		
(a) Primary Sludges						
Saginaw, Mich.	−0.38	16	9.9	0	8.5	54
Providence, R. I.	−0.62	5.5	6	2.2	13.0	73
Wyandotte, Mich.*	−0.61	8.0	15	5	8.0	70
(b) Digested-Primary Sludges						
Rockford, Ill.	−0.90	9.5	7.1	5.4	11.5	71.5
Schenectady, N. Y.	−0.75	8.5	6.0	4.0	11.5	77.0
Long Beach, N. Y.†	−0.69	3.8	17.0	3.5	14.0	73.0
Greenwich, Conn.	−1.02	5.6	6.0	3.0	11.0	74.0
Dallas, Tex.	−0.86	7.5	5.5	2.5	14.5	72.5
(c) Elutriated-Digested-Primary Sludges						
Cincinnati, Ohio	−0.66	8.5	0	4.5	3.1	64.0
Toronto, Ont.	−0.43	7.7	0	4.0	8.0	70.0
East Providence, R. I.	−0.60	9.0	0	1.5	20.0	72.5
Dallas, Tex.	−0.50	8.0	0	0.8	15.5	70.5
(d) Digested-Primary-Activated Sludge						
Nassau County, N. Y.	−1.21	4.5	12.0	8.0	3.0	79.0
(e) Elutriated-Digested-Primary-Activated Sludges						
Cranston, R. I.	−0.55	2.4	0	7.0	3.4	85.0
Houston, Tex.	−0.79	2.7	0	5.5	5.5	84.2
Ann Arbor, Mich.	−0.49	5.0	15.0	3.0	5.0	72.5
Cleveland, Ohio	−0.53	5.5	9.0	2.5	6.3	71.5
Hyperion (L. A.), Calif.‡	−0.59	5.1	0	1.9	5.8	76.5

* Sludge hauled to plant from other collecting points in county; therefore, it is somewhat septic, depending on temperature and elapsed time.

† Testing conditions prevented optimum operation.

‡ Separan also added at approximately 0.02 per cent.

by using a control valve in the dry vacuum line. The valve serves to limit the dry vacuum and prevent cake cracking, thereby effecting maximum cake dewatering. It also insures filter operation at the maximum form vacuum and filtration rate. This increase in rate and decrease in moisture generally more than offsets the small additional investment. Figure 8 shows this type of piping layout.

Comparison of Leaf Test, Theory, and Pilot-Plant Test Results

To determine if the data from the leaf tests and controlled tests on the 4-ft. diameter by 2-ft. wide rotary filter at East Lansing were comparable to field test results, a portable pilot-plant sludge filter station was constructed. The unit (Figure 9) included an 18-in. diameter by 12-in.

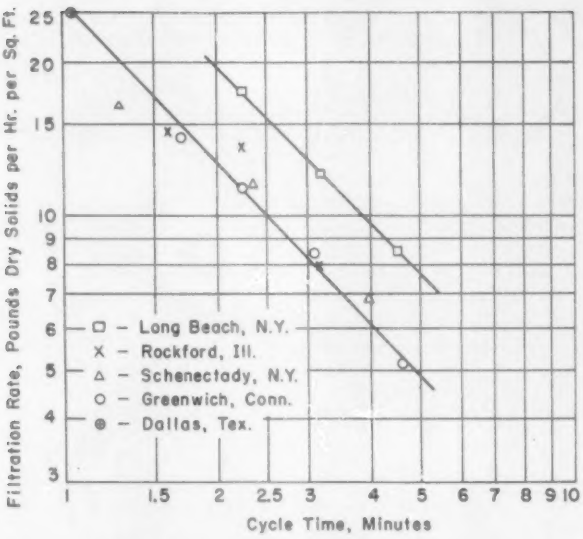

FIGURE 10.—Filtration rate versus cycle time; pilot-plant data; primary-digested sludges; form vacuum, 20 to 25 in. Hg; submergence, 25 per cent.

wide rotary filter and accessories. The equipment was of standard design except for the variable retention time in the mix tank and the variable submergence on the filter. After preliminary testing, however, the mix tank retention was fixed at the minimum value for good mixing (approximately 1 to 2 min.) and the filter submergence was set at 25 per cent. These settings were checked at the various treatment plants where test work was done and they appeared to be nearly optimum for almost all sludges.

Field test work with the trailer unit has been completed at more than 20 plants with five different types of sewage sludges. Due to the difficulty in achieving the proper operating conditions, data from all of the plants were not representative. However, the results from the 18 plants as summarized in Table I are considered typical.

The logarithmic relationship between filtration rate and drum speed as previously discussed was found to be true for nearly every sludge tested. The slopes of these lines are shown in Table I.

It can be seen that the values vary widely, but that in general the results conform well with what would be predicted. That is, the values for the primary sludges varied considerably whereas those for the primary-digested sludges were more nearly equal. When all of the points for these five sludges are grouped (Figure 10), the variance seems slight. Sludge digestion would be expected to minimize the variance in the filtration characteristics because of the evening out of the conditions due to the sludge hold-up and the bacterial action.

The value for the digested-primary-activated sludge was considerably lower than for the other sludges, indicating that it was more difficult to filter. This undoubtedly is due to the difficulty in flocculating the fine particles even with large chemical additions. It can be concluded, therefore, that the logarithmic function ex-

TABLE II.—Operating Conditions* for Results Shown in Figure 11

Plant	Sludge Type	Chemicals (%)		Drum Speed (min./rev.)
		CaO	$FeCl_3$	
East Providence, R. I.	Digested-elutriated	0	3	3.1
East Lansing, Mich.	Primary-activated	10	3	3.4
Cincinnati, Ohio (Little Miami)	Digested-elutriated	0	4.5	3.1

* For a vacuum, 20 to 25 in. Hg; submergence, 25 per cent.

pected from theoretical considerations is true for most sludges and that the range of values shown in Table I is typical for operation at most average plants. Since these slopes are a definite relative indication of the filterability of the sludges, the effect of the various types of plant treatment on the sludge filtration characteristics should definitely be considered in a plant design.

Filtration Rate as a Function of Feed Solids Concentration

As noted previously, it generally is difficult to obtain reliable test results on filtration rate as a function of the solids concentration in the sludge. However, at the East Lansing, Mich., Cincinnati, Ohio, and East Providence, R. I., plants close control of feed solids was possible and good test results (Table II) were obtained. These results are shown graphically in Figure 11. It is evident from these data that a linear function can be expected but that the slope of the curves will vary rather widely. The most significant conclusion that can be drawn from the data is that the indications from the leaf test data are correct. Even with

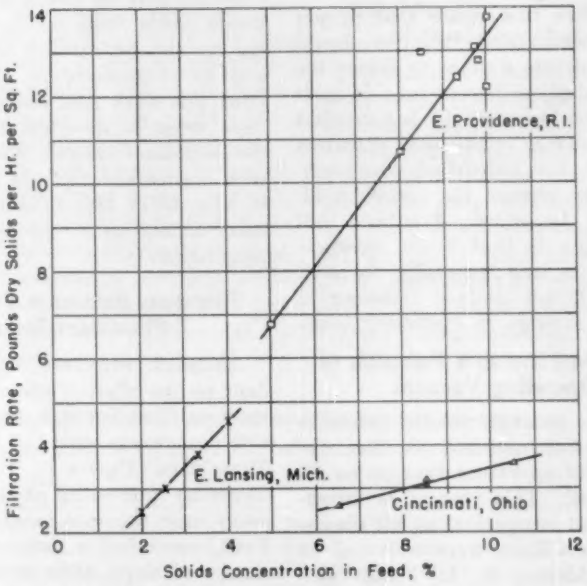

FIGURE 11.—Filtration rate versus feed solids concentration; pilot-plant data; operating conditions as in Table II.

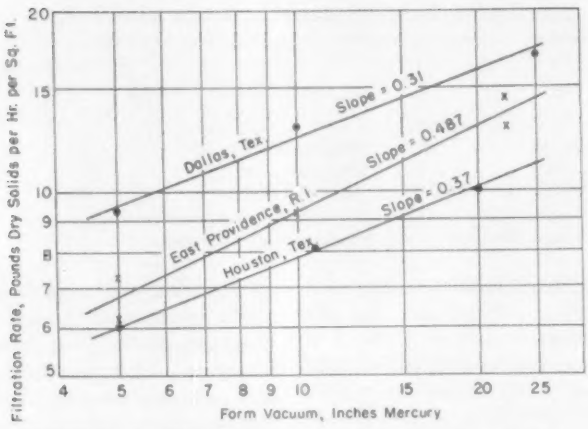

FIGURE 12.—Filtration rate versus form vacuum; pilot-plant data.

the sludge at Cincinnati, which exhibited the least effect of concentration, a 33 per cent increase in sludge solids resulted in a 20 per cent increase in filtration rate. For the East Providence sludge a 33 per cent solids increase resulted in a rate increase of more than 30 per cent.

In practice this means that proper sludge concentration facilities should be designed into a plant to insure the lowest total plant investment. In most cases thickening capacity is somewhat less expensive to install than filtration equipment, but individual plant conditions may change the specific relationships. An added advantage (not shown here) is that lower chemical consumptions can generally be used with the thicker sludges, resulting in a definite savings in operating costs.

Filtration Rate as a Function of Operating Vacuum

To insure accurate results, extensive test work was required to show the true effect of operating vacuum on filtration rates. This type of investigation was not economical at all plants, but sufficient data were collected at East Providence, R. I., Dallas and Houston, Texas, to confirm the logarithmic relationship obtained from the leaf test data (see Figure 5). Figure 12 shows the functions obtained from the data at these three plants. The Houston sludge is elutriated-digested-primary-activated; the others, elutriated-digested-primary.

As discussed previously, it would be expected that the slopes of these curves would range from 0.3 to 0.5, depending on the filterability of the sludge and its characteristics. It is evident from this work that vacuum filter stations must be designed to operate at the maximum vacuum level obtainable with economical vacuum pumps (that is, 20 to 25 in. Hg) to obtain the maximum utilization of the potential filter production.

Filtration Rate as a Function of Flocculant Dosage

Although extensive work was not done on the effect of chemical addition rates on filtration rate, the ferric chloride dosage was varied at three plants. These data (Figure 13, Table III) indicate an interesting phenomenon. In every case the rate-versus-percentage-$FeCl_3$ curve had a definite and sharp change of slope, after which increased chemical additions gave little or no increase in rate.

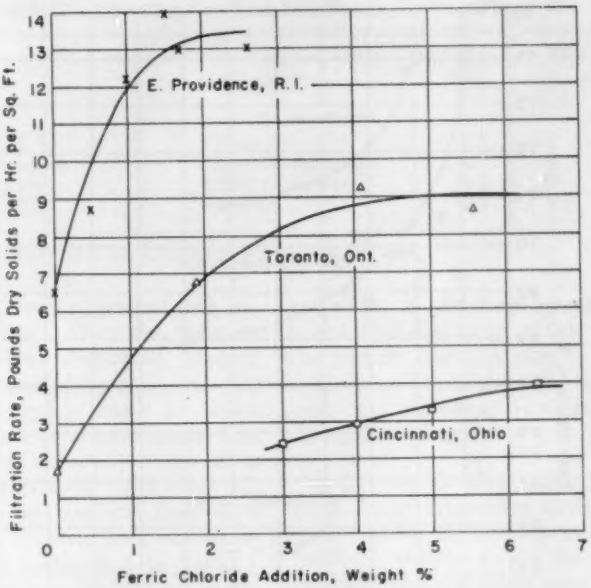

FIGURE 13.—Filtration rate versus ferric chloride addition; pilot-plant data; operating conditions as in Table III.

It is obvious that a plant should operate as close to this "hump" in the curve as possible to achieve most economical operation. The tests have shown that in most plants, particularly those with digesters, the sludge characteristics do not change radically within a short time; hence, periodic checks with a simple leaf test technique could insure operation with close to the most economical chemical additions. The savings associated with this type of operation are well known to all plant operators.

Cake Moisture as a Function of Operating Variables

The analysis of cake moisture as a function of the operating variable previously discussed is less definitive, as the moistures apparently vary more widely with specific feed conditions. Cake moisture is definitely a function of drying vacuum, chemical dosage, and drying or cycle time. Although the data are not completely conclusive, it appears that any chemicals added beyond the optimum dosage as shown on the rate-versus-chemical addition

TABLE III.—Operating Conditions* for Results Shown in Figure 13

Plant	Sludge Type	Feed Solids (%)	Drum Speed (min./rev.)
East Providence, R. I.	Digested-elutriated	8–10	3.1
Toronto, Ont.	Digested-elutriated	7.2–8.4	4.25
Cincinnati, Ohio	Digested-elutriated	10.4	3.4

* Form vacuum, 20 to 25 in. Hg; submergence, 25 per cent.

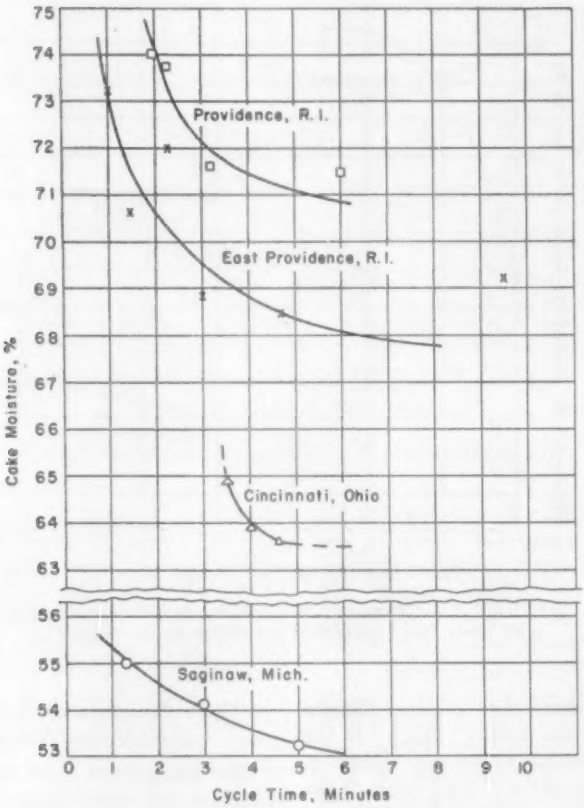

FIGURE 14.—Cake moisture versus drying time; pilot-plant data; operating conditions as in Table IV.

curve would not be economical. Some additional moisture reduction can probably be obtained, but unless a dryer or incinerator were a severe limitation in a plant, the moisture reduction by this means would be uneconomical due to the increased cost of chemicals versus additonal cost of fuel. It appears advisable, therefore, to set the chemical addition by the filtration rate instead of the cake moisture.

Drying vacuum also has a definite effect on cake moisture and filters should be operated at the highest possible vacuum. As outlined previously, if cake cracking is expected a two-receiver vacuum system is recommended. This will prevent any excess air from being drawn through a cracked cake and will result in minimum cake moistures at the lowest horsepower demand. If the cake does not crack, a vacuum of 20 to 25 in. Hg should be maintained unless specific local conditions are such that a wet or partially dewatered cake is desired. In most cases, however, this situation would not exist.

The variable that has the greatest effect on cake moisture and can commonly be controlled in a plant is drying or cycle time. Figure 14 and Table IV show the same relationship for several of the sludges tested with

TABLE IV.—Operating Conditions* for Results Shown in Figure 14

Plant	Sludge Type	Feed Solids (%)	Chemicals (%)	
			Lime	$FeCl_3$
Providence, R. I.	Primary	5.5	7	3
East Providence, R. I.	Digested-elutriated	4	0	1.3
Cincinnati, Ohio	Digested-elutriated	6.7	0	6.5
Saginaw, Mich.	Primary	16.4	9.9	0

* Drying vacuum, 20 to 25 in. Hg; submergence, 25 per cent.

the trailer unit as was evident with the leaf test results. After the cake essentially has been dewatered, little if any benefit is gained by a longer cycle or additional drying time. As shown on the filtration rate-versus-cycle time curves, the rate definitely drops off as cycle time is increased. For more difficult to filter sludges this drop-off is sharp, as can be seen from the slopes of the curves summarized in Table I. It is advantageous, therefore, to operate with the proper balance between drum submergence and cycle time to give the combination of drying and form time which is desired.

To show the relationship between rate and moisture on a plant filter is generally difficult. Therefore, a simple test method is necessary to serve as a check on the filter operation and help set the optimum operating conditions. The method must allow for the effects of these variables on both filtration rate and cake moisture. It is believed that because of the close correlation between the leaf test results outlined herein and the pilot plant data, this technique can be used dependably. If the sludge composition changes rapidly any test technique will be of limited value, but in most plants a few check runs per shift yielding the data as shown will aid immeasurably in fixing the optimum chemical addition and the cycle time required to give the desired or lowest cake moisture. If filter capacity is a limitation and cake moisture is not critical, the filters should be operated with the optimum chemical addition and at the fastest drum speed that will give a good discharge, as this will yield the highest filtration rate.

In using these data for design criteria, the following recommendations are made:

1. Investigate thoroughly the optimum sludge thickening methods to insure highest sludge concentration to the filter, thereby giving the lowest investment and operating costs.

2. Provide sufficient flexibility in the filter station to allow easy changing and control of the chemical addition so that the operator can make the necessary adjustments with the least labor.

3. Check the operation of several sludge filters on similar sludges, if possible, to determine the average performance. The data indicate conclusively that there is variance in filtration characteristics of similar sludges, but that plant treatment has definite and large effects on the filtration characteristics of the sludge. The average values which can be obtained from such checking at other plants should serve as a reasonable basis for average plant design.

4. Even for small filter stations the use of a vacuum control system should be considered, as the initial cost is low and lower operating costs definitely can result. It has been shown clearly that the highest possible vacuum should be maintained to give the greatest filtration rate and lowest cake moisture and this can be done economically with such a system.

It is hoped that this type of leaf test technique and analysis will be of value in determining sludge filter station design and the optimum conditions for an operating plant. It would be impossible to acknowledge all of the valuable help and advice given by the operators at the plants where the test work was done, but the authors wish to express their appreciation to these plant personnel as well as those at Michigan State for their help and valuable guidance.

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References

1. Wilson, J. A., and Heisig, H. M., "The Role of Acidity in the Dehydration of Sewage Sludge." *Ind. Eng. Chem.*, **13**, 5, 406 (1921).
2. Wilson, J. A., Copeland, W. R., and Heisig, H. M. "A Preliminary Study of the Activated Sludge Process." *Ind. Eng. Chem.*, **14**, 2, 128 (1922).
3. Mohlman, F. W., "The Filtration of Activated Sludge." *Ind. Eng. Chem.*, **16**, 3, 225 (1924).
4. Mohlman, F. W., and Edwards, G. P., "Prefiltration Treatment of Sewage Sludge." *Ind. Eng. Chem.*, **26**, 2, 226 (1934).
5. Genter, A. L., "Adsorption and Flocculation as Applied to Sewage Sludges." *Sewage Works Jour.*, **6**, 4, 689 (July, 1934).
6. Halff, A. H., "An Investigation of the Rotary Vacuum Filter Cycle as Applied to Sewage Sludges." THIS JOURNAL, **24**, 8, 962 (Jan., 1952).
7. Beck, A. J., Sakellariou, E. N., and Krup, M., "A Method for Evaluating the Variables in Vacuum Filtration of Sludge." THIS JOURNAL, **27**, 6, 689 (1955).
8. Carman, P. C., "Fundamental Principles of Industrial Filtration." *Jour. Inst. Chem. Eng.*, **16**, 168 (1938).
9. Perry, J. H., "Chemical Engineer's Handbook." McGraw-Hill Book Co., New York, N. Y. (1950).
10. Nickalous, N., and Dahlstrom, D. A., "Theory and Practice of Continuous Pressure Filtration." Spring National Meeting, Amer. Inst. Chem. Eng., Springfield, Mass. (May, 1954).
11. Schepman, B. A., Martin, B., and Dahlstrom, D. A., "Analysis of Fundamental Variables Affecting Filtration of Corn Gluten." Spring National Meeting, Amer. Inst. Chem. Eng., Houston, Tex. (May, 1955).
12. Brown, G. G., "Unit Operations." John Wiley & Sons, New York, N. Y. (1950).
13. Silverblatt, C. E., and Dahlstrom, D. A., "The Effect of Viscosity and Surface Tension Upon the Moisture Content of a Fine Coal Filter Cake." 20th Annual Chem. Eng. Symposium on Flow Through Porous Media, Amer. Chem. Soc., Ann Arbor, Mich. (Dec., 1953).

PROFESSIONAL OPPORTUNITY

New York—The Division of Laboratories and Research, New York State Department of Health, is accepting applications from qualified individuals for two vacancies in the Division for Senior Sanitary Chemists; one for potable water laboratory work and the other for industrial waste studies. Requirements include a degree in chemistry and four years of experience in sanitation laboratory work. Salary range, $5,882 to $6,620.

Inquiries should be addressed to Wallace W. Sanderson, Assistant Director, Laboratories for Sanitary and Analytical Chemistry, Division of Laboratories and Research, New York Department of Health, Albany 1, N. Y.

A COLORIMETRIC METHOD FOR DETERMINING DISSOLVED OXYGEN

By Charles S. Oulman and E. Robert Baumann

Respectively, Research Associate and Associate Professor of Sanitary Engineering, Engineering Experiment Station, Iowa State College, Ames, Iowa

The Winkler Method with its modifications (1) is widely used for the determination of dissolved oxygen in water and sewage, and is generally accepted as the standard method. Manganous sulfate is reacted with oxygen in the sample to give manganic hydroxide. Upon acidification of the manganic hydroxide in the presence of an alkaline iodide solution, some of the iodide is liberated as free iodine in the following reaction:

$$2Mn(OH)_2 + O_2 \xrightarrow{KOH} Mn_2O_2(OH)_2$$

$$Mn_2O_2(OH)_2 + 2KI + 2H_2SO_4 \rightarrow 2MnSO_4 + 2H_2O + 2KOH + I_2$$

The amount of iodine released is equivalent to the oxygen originally present in solution. The free iodine is measured by titrating the sample with 0.25 N sodium thiosulfate solution using starch as an indicator. Since the Winkler Method is an indirect iodometric method, reagents may be used in excess. This makes the preparation of samples for analysis easy and eliminates the need for highly standardized reagents. Titration of the iodine is, however, time consuming and a tedious part of the analysis.

Colorimetric methods of analysis can be and have been used to simplify dissolved oxygen determinations. Several colorimetric modifications of the Winkler Method have been proposed that depend upon visual comparison of the color produced in the samples with prepared standards (2) (3). Briggs *et al.* (4) recently described equipment for making continuous dissolved oxygen determinations in stream water. The operation is based on the use of Winkler reagents. The intensity of the color of the iodine solutions, and, therefore, the concentration of dissolved oxygen, are measured with a spectrophotometer.

In a study of the preaeration of sewage conducted at the Ames, Iowa, sewage treatment plant, so many dissolved oxygen determinations were made that the volumetric method of analysis was inconvenient. Therefore, a spectrophotometer was calibrated for colorimetric determination of the iodine released in the Winkler Method for dissolved oxygen.

Spectrophotometer Calibration

A Bausch and Lomb Spectronic 20 Colorimeter was calibrated for use in the dissolved oxygen determinations. A calibration curve must be prepared because the resolution of the instrument depends on the optical density and size of the sample holders that are used as well as the optical system of the colorimeter. Bausch and Lomb 3/4-in. selected test tubes were used as sample holders.

It was first necessary to determine experimentally the wave length of the light to be used in the calibration. This was accomplished by plotting a spectrophotometric graph of per cent transmittance versus wave length for several known concentrations of iodine in distilled water (Figure 1). The iodine solutions were prepared by the Winkler Method and were analyzed by titration with 0.25 N sodium thiosulfate solution. A portion of each iodine solution was analyzed in the spectrophotometer to determine per

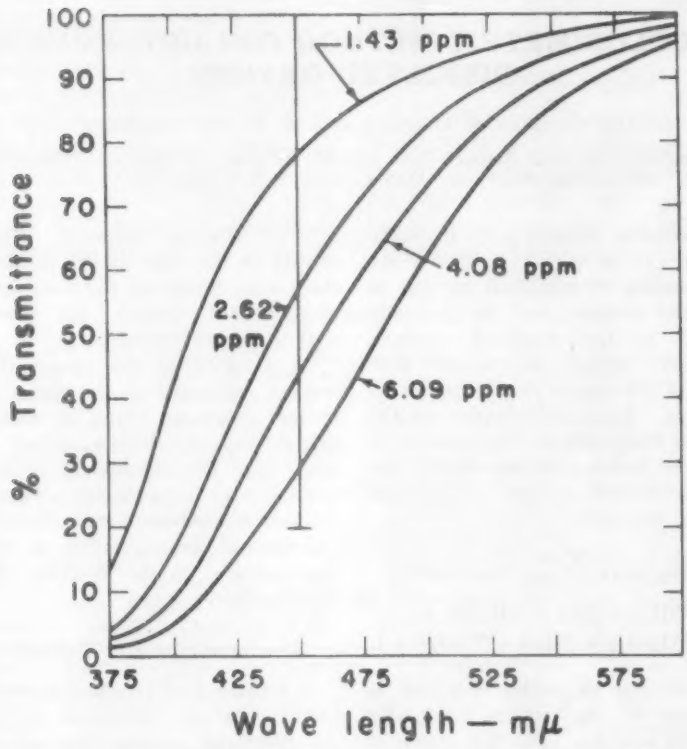

FIGURE 1.—Effect of wave length on the per cent transmittance of light through dissolved oxygen samples containing Winkler reagents.

cent transmittance at the various wave lengths.

The spectrophotometer was calibrated at 450 mμ (millimicrons). Several factors were considered in selecting this wave length. The concentrations of dissolved oxygen in the sewage and B.O.D. samples were expected to range from 0 to 7 or 8 p.p.m. With the Spectronic 20, best accuracy can be attained for transmittance values above 20 to 25 per cent. These requirements could best be fulfilled, using a wave length of light of 450 mμ.

Ordinarily, it is preferable that calibrations be made at wave lengths where absorption is a maximum. A steeply rising or falling section of the curve should be avoided because a small error in setting the wave length could produce a large error in per cent transmittance. The shape of the iodine transmittance curve is such that it is impossible to meet this requirement unless the iodine solution is diluted prior to analysis. In addition to complicating the analysis, diluting the iodine solution introduces a certain amount of error. Since wave length settings may be made precisely on the spectrophotometer, dilution of the iodine solution was not justified.

Iodine solutions used in the instrument calibration were also prepared by the Winkler Method using distilled water. The per cent transmittance of each sample was plotted against the dissolved oxygen in the sample as measured by titration (Figure 2).

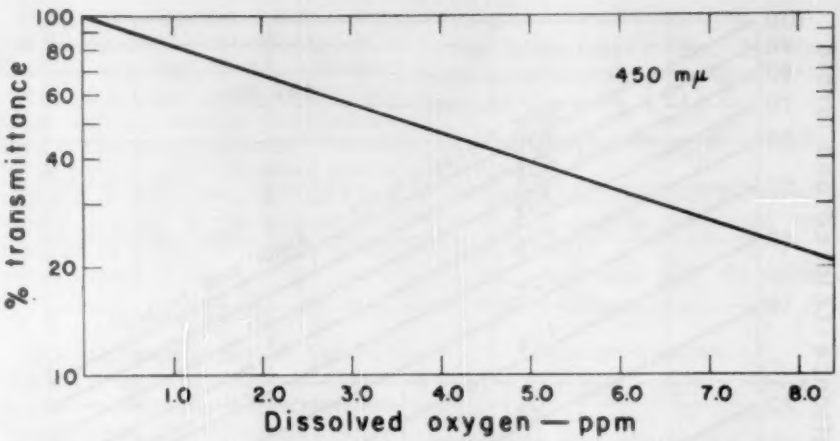

FIGURE 2.—Spectronic 20 calibration curve for dissolved oxygen in non-turbid samples.

Turbidity Correction

It is necessary to correct for turbidity when analyzing sewage or turbid water colorimetrically for dissolved oxygen. When a spectrophotometer is used as a colorimeter it is insensitive to the nature of the light-absorbing material in the sample. The intensity of the light reaching the photoelectric cell is the only thing that is measured. The turbidity might be removed directly by filtration. However, part of the iodine is oxidized too, therefore consistent results cannot be obtained.

Good results, however, may be obtained with an indirect method. Two measurements (per cent transmittance) are made on each sample. The first is with the turbid, iodine-colored solution; the second with the turbid solution alone, the iodine color having been destroyed by oxidation with sodium thiosulfate. The correction for turbidity may be derived from the combined Lambert-Beer law and the definition of per cent transmittance:

$$\log. T = -\epsilon lc = \log. 100 \qquad (1)$$

where

T = per cent transmittance;
ϵ = the molar extinction coefficient;
l = the length of the light path through the sample; and
c = the concentration of the substance in solution.

The turbidity in the sample is equivalent to a concentration of iodine having the same per cent transmittance. This concentration of iodine will be referred to as "the concentration of iodine that is turbidity."

Then, if

A = the per cent transmittance of the turbid, iodine colored solution;
B = the per cent transmittance of the turbid solution alone;
C = the per cent transmittance of the iodine solution alone;
c_i = the actual concentration of iodine in solution; and
c_t = the "concentration of iodine that is turbidity."

Then

$$\log. A = -\epsilon l(c_t + c_i) + \log. 100 \qquad (2)$$

$$\log. B = -\epsilon lc_t + \log. 100 \qquad (3)$$

$$\log. C = -\epsilon lc_i + \log. 100 \qquad (4)$$

$$\log. A = \log. B + \log. C - \log. 100 \qquad (5)$$

or,

$$C = \frac{A}{B}\,100 \qquad (6)$$

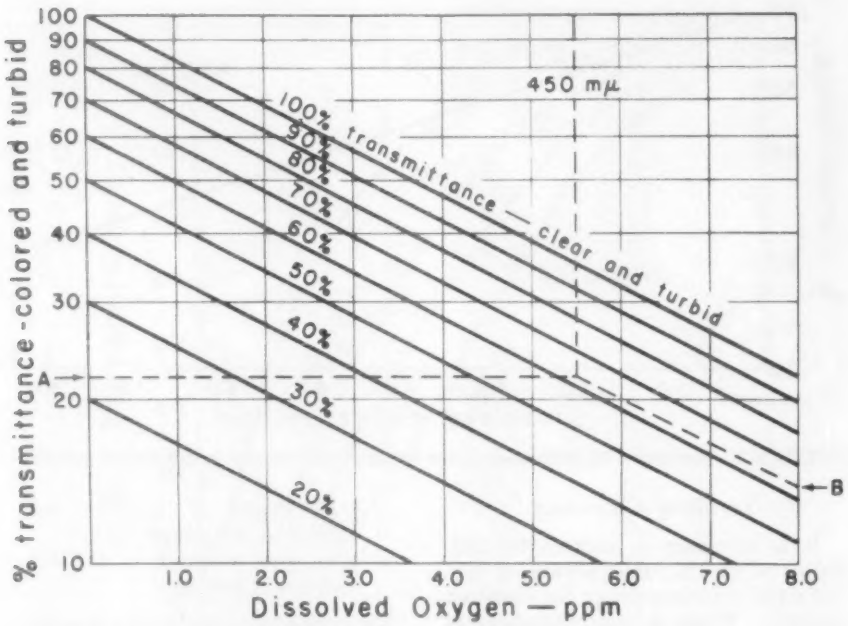

FIGURE 3.—Spectronic 20 calibration curve for dissolved oxygen in turbid samples.

Eq. 6 may be used to correct the spectrophotometer reading for turbidity, or a family of calibration curves with turbidity a parameter may be plotted from the original calibration curve and the relationship that has been derived. Figure 3 shows the family of curves derived from Figure 2.

Example:

The use of this curve can best be explained as follows:

A sewage sample is prepared for dissolved oxygen analysis by the Winkler Method. A portion of the sample is poured into a ¾-in. test tube and the tube is inserted in the spectrophotometer. The per cent transmittance of the turbid, iodine colored solution is 22 (Line A, Figure 3). One drop of 10 N sodium thiosulfate solution is added to clear the iodine color. The per cent transmittance of the turbidity in the sample is found to be 63 (Line B, Figure 3). The dissolved oxygen in the sewage sample is 5.5 p.p.m.

Calibration Use

The colorimetric method has been in use for more than six months at the Ames, Iowa, sewage treatment plant for B.O.D. work. No correction for turbidity has been necessary because the sewage was sufficiently dilute in the samples. Therefore, the 100 per cent line on the calibration curve was converted to tabular form for additional convenience.

A batch of 12 to 15 B.O.D. samples can be prepared for analysis and analyzed colorimetrically in less than 30 min. Formerly it was necessary to standardize a solution of sodium thiosulfate and titrate each sample. The time saved in routine B.O.D. analysis is approximately one-half to three-quarters of an hour each time B.O.D. determinations are run.

Samples for in-plant dissolved oxygen determinations are collected in a standard type sampler (1). Winkler reagents are added as the samples are taken and the samples are analyzed with the spectrophotometer. Turbidity is present in nearly every sample collected in the plant and Figure 3 is used to convert the spectrophotometer readings to parts per million of dissolved oxygen.

Method Accuracy

The colorimetric method has been checked periodically against titrated samples to determine whether the calibration would remain constant. It appears that the calibration will remain definite.

The iodine solution was found to behave according to the Lambert-Beer law. Therefore, it would have been necessary to establish only one point to draw the calibration curve. Several points were determined, however, to eliminate errors in titration.

The error in the method is increased when turbidity is present. In the first place, two readings are taken instead of one. Secondly, the addition of a drop of sodium thiosulfate to the sample to clear the iodine color causes a slight dilution. The per cent transmittance is thus increased by a slight amount. Finally, the total error is inversely proportional to the per cent transmittance of the turbidity in the sample, *i.e.*, the error is twice as large at 50 per cent transmittance as at 100. These errors seem to be negligible, however, for the results closely check those obtained by titration.

Conclusions

The advantages claimed for the colorimetric modification of the Winkler Method are:

1. The standardization of solutions is eliminated.
2. Time spent in analysis is reduced.
3. The method is easier and less tedious to use.
4. The correlation with the standard method is direct.

Acknowledgments

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The authors gratefully acknowledge the cooperation and constructive criticisms of Ralph Briley, Chief Operator, Sewage Treatment Plant; Harris F. Seidel, Superintendent, Water and Sewage; and Clifford V. Smith, former Assistant to the Superintendent, Ames, Iowa.

References

1. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).
2. Rideal, S., *Jour. Soc. Chem. Ind.*, **20**, 1074 (1901).
3. Snell, F. D., and Snell, C. T., "Colorimetric Methods of Analysis." 3rd Ed., D. Van Nostrand Co., Inc., New York, N. Y. (1953).
4. Briggs, R., Knowles, G., and Scragg, L. J., "A Continuous Recorder for Dissolved Oxygen in Water." *Analyst*, **79**, 744 (1954).

Industrial Wastes

EVALUATION OF BROAD FIELD DISPOSAL OF SUGAR BEET WASTES

By Glen J. Hopkins, Joe K. Neel, and Francis L. Nelson

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Performance of the broad field disposal area receiving wastes from the Bayard, Nebr., refinery of the Great Western Sugar Company was evaluated in 1953 (1). This study indicated a substantial reduction of the factory waste load, but pointed out several aspects in which design and maintenance improvements would enhance the degree of treatment effected. A number of revisions were completed prior to the 1955 sugar beet campaign and another study appeared appropriate. Accordingly, arrangements were made to perform another cooperative study in October 1955.

Modifications and additions made by the sugar company since the 1953 campaign included a welded steel header flume replacing the wooden sided ditch that had allowed many washouts, metal distribution flumes instead of 4-in. pipes, elevation of dikes along the drainage ditch and waste canal to prevent short circuiting, and three shallow 5-acre lagoons formed by corrugated metal cross weir connections between two infield longitudinal dikes (Figure 1).

The study, carried out during the week of October 23, 1955, was restricted to the disposal area. The objectives were: (a) evaluation of the over-all efficiency of the disposal system, (b) determination of the purification accomplished in various segments of the grassland area, (c) determination of detention time and flow patterns, and (d) comparison of waste reduction performed by grasslands and shallow lagoons of equal area.

Description

The land disposal area, except for modifications previously listed, was essentially as described (1) for the 1953 campaign. The two earthen dikes forming the eastern and western boundaries of the lagooned section (Figure 1) divided the upper half into three longitudinal sections. Parshall flumes measuring discharge at the inlet and from the outlet collection ditch were the same installations used in 1953. The rotary screen, operated ahead of the header flume in 1953, had been removed.

Metal distribution flumes were spaced on 50-ft. centers (25 ft. between the last two) along the header flume. Sections I and II received discharge from 10 of these flumes; Section III was supplied by 11. Lagoon bottoms were only partially leveled, consequently the second and third lagoon areas did not become completely covered with liquid.

Modifications within the plant subsequent to the 1953 study permitted discharge of pulp press water to the disposal area. The 12-in. line leading directly to the drainage ditch carried only the wastes from the elevated dewatering bin and coal storage and drippage pits. In other respects factory operation was in accord with the flow diagram appearing in the report of the 1953 study (1).

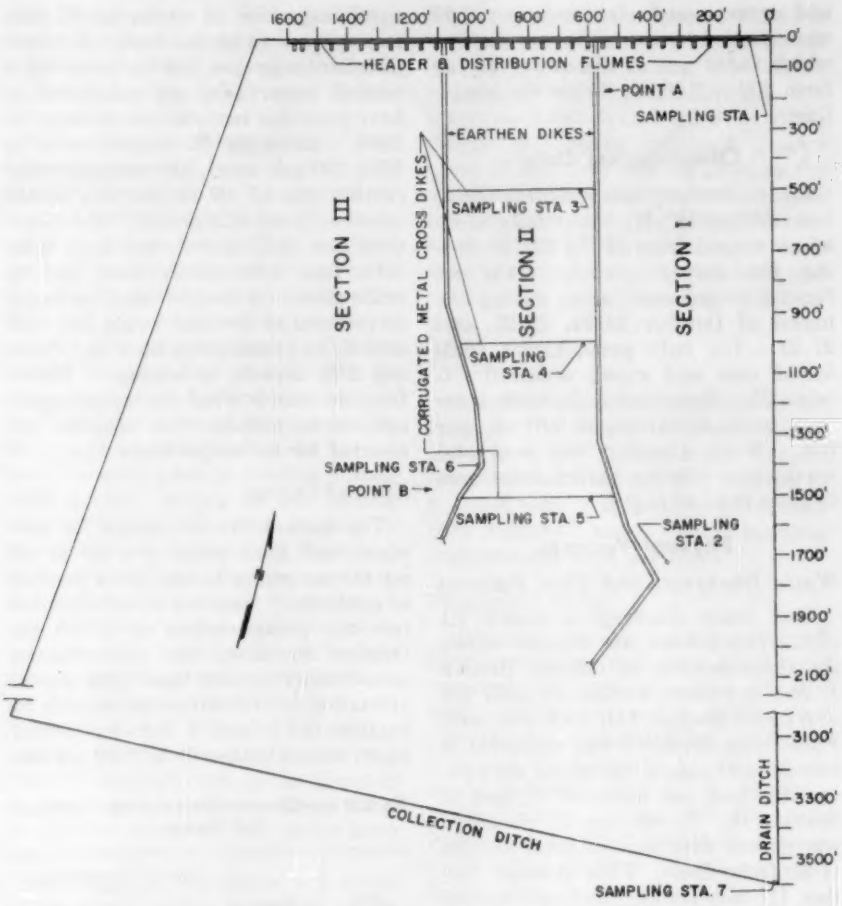

FIGURE 1.—Layout of waste treatment field at Great Western Sugar Co., Bayard, Nebr.

Procedures

Sampling points were located to evaluate raw waste, field effluent, discharges from each longitudinal section, and overflow from each of the three lagoons (Figure 1). Three 24-hr. composites collected at each station were analyzed for turbidity, settleable solids, suspended solids, pH, alkalinity, dissolved oxygen, and biochemical oxygen demand. Additional oxygen tests were run on grab samples from routine stations and selected areas on the field. Coliform analyses were performed on five daily grab samples at Stations 1 through 7. Samples for nitrogen cycle, phosphate, plankton, and bottom organisms were collected at routine stations. In addition, samples for the last two were obtained from selected areas. Analyses were according to "Standard Methods" (2).

Time of flow through the field was measured by introducing one ton of salt into the pump suction and checking the time of passage to Stations 2, 5, and 7, by hourly chloride analysis at each point for 44 hr. Time of flow

and current paths in the upper field were studied by use of fluorescein dye, which faded out at distances varying from 200 to 2,000 ft. below the header flume.

Climatological Data

Maximum daily temperatures varied from 56° to 78° F., while daily minimums ranged from 21° to 37° F. during the survey period. Thin ice formed in quiescent areas during the nights of October 23–24, 26–27, and 27–28. The only precipitation (0.20 in. of rain and snow) occurred October 23. Evaporation (corrected for land surfaces) averaged 0.07 in. per day. Wind direction was west and northwest; velocity varied from zero to more than 25 m.p.h.

Physical Features

Waste Discharges and Flow Patterns

Raw waste discharge averaged 7.1 c.f.s. This volume was divided among the three sections as follows: Section I, 28.1 per cent; Section II, 30.5 per cent; and Section III, 41.4 per cent. Flow down Section I was restricted to two main channels, one along the eastern dike and one about 50 ft. east of Section II. In Section II discharge was mainly over the southeast corners of all three dams. Flow through Section III was mainly southeast toward Section II until diverted west by the remnants of old dikes extending diagonally across the field at about the 700- and 1,500-ft. points. A permanent marshy area extending from northwest to southeast in Section III was flooded with wastes. Major flow from all three sections joined below Section II and, after some spreading, finally entered the collection ditch in a wide area slightly east of center. Effluent discharge averaged 5.45 c.f.s., indicating a mean loss of 1.65 c.f.s. on the disposal area.

The water-covered area of the field could only be estimated. In 1953 it was assumed to be 60 per cent, which, upon inspection of recent aerial photos, appears to be too high. A better distribution system and the cross-diked central upper area are considered to have provided more water coverage in 1955. Assuming 32 wetted acres in 1955 (20 per cent), the average evaporation rate of .07 in. per day would consume about 0.18 acre-ft. The measured loss (3.27 acre-ft. per day) indicates that 3.09 acre-ft. were lost to infiltration. A wetted area covering 60 per cent of the field would lose 0.55 acre-ft. to evaporation each day, leaving 2.72 acre-ft. to seepage. Therefore, no matter what the water coverage, it is evident that seepage accounted for the major water loss.

Time of Passage

The normal chloride range for raw waste and field water was 25 to 30 p.p.m., according to the Mohr method of analysis. One ton of salt dumped into the pump suction at 11:30 AM October 26 raised the concentration momentarily to more than 5,000 p.p.m. at Station 1. Variations in chloride at Stations 2, 5, and 7 for the period 12:00 NOON October 26 to 7:00 AM Oc-

TABLE I.—Chloride Concentration Following Salt Dosage

Date (1955)	Time	Chloride Concentration (p.p.m.)			
		Sta. 1	Sta. 2	Sta. 5	Sta. 7
Oct. 26	12 NOON	>5,000*	25	—	—
	4 PM	25†	25	26	—
	8 PM	—	25	25	25
	12 MID.	—	97‡	26	27
Oct. 27	4 AM	—	85	26	30
	8 AM	—	59	37§	42
	12 NOON	—	41	43	43‖
	4 PM	—	32	37	38
	8 PM	—	31	32	40
	12 MID.	—	33	34	58
Oct. 28	4 AM	—	32	36	38

* At 11:30 AM after being added at 11:15 AM (200 p.p.m. at noon).
† From 1 PM on.
‡ Peak at 165 p.p.m. at 9 PM.
§ Peak at 47 p.p.m. at 1 PM.
‖ Peak at 45 p.p.m. at 10 to 11 AM.

tober 28 are given in Table I. Maximum chloride concentrations appeared at Station 2 after 9.5 hr. had elapsed, at Station 5 after 25.5 hr., and at Station 7 after 22.5 hr.

From these results it appears that most water starting down the first, and possibly the third, section arrived at the field outlet within 24 hr. The cross weirs in the second section retarded flow and it took 24 hr. to traverse 1,500 ft. Water leaving Section II may have had some influence in maintaining chloride concentration at Station 7 after the peak had passed. The lagoons more than doubled retention in the first 1,500 ft. and increased chlorides were apparent after 44 hr. A lower chloride peak at Station 5 indicated greater mixing in the lagoons than in Section I above Station 2. Persistence of chloride at Station 5 after Station 2 was back to normal is also indicative of greater retention.

In 1953 some added chloride was recovered at the outlet within 4 hr., the maximum concentration occurred 14 hr. after dosage, and within 30 hr. all traces of added chloride had disappeared. Greater retention in 1955 apparently resulted from better dispersal of raw waste. Lagoons more than doubled the retention time under these circumstances.

One pound of fluorescein was added to the pump suction at 11:00 AM on October 28 and the dye was traced down each section of the field until it disappeared. In the flowing stream along the eastern boundary of Section I the dye moved 2,000 ft. downfield in 2 hr. 8 min. It covered 600 ft. in 12 min., 1,200 ft. in 28 min., and 1,500 ft. in 49 min. In the western current path the dye appeared at 1,200 ft. in 3 hr. 27 min. There it required 31 min. to extend 400 ft. In Section II the dye traveled 1,300 ft. in 3 hr. 27 min. along the eastern dike, but apparently moved more slowly along the western side of the lagooned area, where it disappeared in a green algal bloom 200 ft. below the header flume. Twenty-seven minutes passed before it reached this point, whereas it moved 200 ft. in 11 min. along the eastern boundary. In Section III the dye traversed 1,100 ft. in 3 hr. 5 min. Although fluorescein indicated greater speed of flow than was indicated by the chloride studies, the latter are considered more accurate indices of retention time. Fluorescein has a tendency to spread over water surfaces and its dispersal is facilitated by wind action.

Temperature

The raw waste temperature varied from 30° to 34° C. Effluent varied from 6° to 18° C. and other stations ranged from 5° to 19° C. Stations 3, 4, and 5 were usually 1° to 5° warmer than Stations 2 and 6. Early morning temperatures were not taken.

Suspended Solids

Settleable solids quickly dropped from suspension and were completely removed in upper reaches of the field. Other suspended solids were also rapidly eliminated by precipitation and the quantity left in the effluent indicated 99 per cent removal. Some increase in concentration was occasioned by algal growth in Section II, in which all three lagoons averaged higher than Sections I and III.

Turbidity

Turbidity had much the same fate as suspended solids; more than 99 per cent reduction was afforded by the disposal area, major reduction resulted from sedimentation in the upper region, and algal growth brought about increases in lagoons in Section II.

Chemical Features

Oxygen

Oxygen occurred in trace quantities in the raw waste, but was absent in the effluent and at all sampling points in the field. In 1953 it occurred sparingly in areas containing clear brown

TABLE II.—Biochemical Oxygen Demand Data

Sampling Point	Individual B.O.D. Measurements (p.p.m.)			Average B.O.D. (p.p.m.)
	Oct. 24	Oct. 25	Oct. 26	
Sta. 1	499	463	492	485
Sta. 2	200	229	320	250
Sta. 3	251	242	355	283
Sta. 4	241	216	288	248
Sta. 5	258	219	226	234
Sta. 6	241	242	376	286
Sta. 7	241	200	215	219
12-in. sewer	139	117	162	139
To Sect. I	—	—	439	—
To. Sect. II	—	—	451	—
To Sect. III	—	—	430	—

water and upon occasion in trace quantities in the effluent.

B.O.D.

B.O.D. measurements are given in Table II. On the average the lagooned Section II removed a greater percentage of B.O.D. than did comparable upper reaches of Sections I and III. Average concentration in the effluent indicated a total removal of 55 per cent of the applied concentration. In 1953 the average B.O.D. of the raw waste was 483 p.p.m. and that of the effluent 158 p.p.m., a reduction of 67 per cent. Yet, in 1953, 11,200 lb. were applied per day, whereas the 1955 loading was 18,560 lb. per day. In 1953, 8,214 lb. were removed each day, but the 1955 daily removal was 12,127 lb. The field discharged 6,433 lb. per day in 1955 and only 2,990 lb. in 1953; however, in 1953 more wastes were bypassed around the field and the total amount of B.O.D. discharged to the river was considerably less in 1955. The drainage ditch carried 10,470 lb. per day into the river in 1953, but in 1955 the ditch carried only 8,031 lb. per day, due chiefly to the reduction of wastes discharged to the 12-in. sewer, whose B.O.D. was reduced from 337 p.p.m. in 1953 to 139 p.p.m. in 1955. In-plant improvements that led to greater application of wastes to the land disposal area and elimination of short-circuiting from the field to the drain ditch were of considerable value in reducing the B.O.D. load to the river in 1955.

On October 26, 1955, samples were composited from all distributor flumes leading to each section to determine apportionment of the total load among the three sections of the field. Variation in concentration (Table II) was not extreme. Total load per day to each section, as well as removal, is given in Table III. The total divided load (18,335 lb.) is very close to the daily average waste load of 18,560 lb. In comparing B.O.D. removal in Sections I and III it may appear that greater waste load was responsible for the poorer showing of the third section. However, Section III removed fewer pounds than did the other sections. Section II received a heavier loading than Section I, but still effected greater B.O.D. reduction.

TABLE III.—Division of B.O.D. Load to Three Field Sections

Section	B.O.D.		
	Total Load (lb.)	Removal (lb.)	Removal (%)
I	5,158	1,398	27
II	5,737	2,862	50
III	7,440	935	12.5

Tons of beets processed and pounds of B.O.D. produced during each 24-hr. composite period are shown in Table IV. On the average, 9.7 lb. of B.O.D. were discharged to the field for each ton of beets processed.

Wastes going through the 12-in. sewer directly to the ditch would give a slightly higher B.O.D. value per ton of beets processed. Flow in that sewer was not measured in 1955. In 1953, when flow through the 12-in. line was included, a ton of beets produced 8.7 lb. of B.O.D.

The effluent of the field contained, on the average, 3.36 lb. of B.O.D. per

TABLE IV.—Relationship of B.O.D. Load to Quantity of Beets Processed

Period* (1955)	Beets Processed (tons)	B.O.D.				
		Conc. (p.p.m.)	Total (lb.)	To Field (lb./ton)†	In Effl. (lb./ton)†	Removal (%)
Oct. 23–24	1,856	499	19,096	10.3	3.8	63
Oct. 24–25	1,920	463	17,718	9.2	3.05	66
Oct. 25–26	1,951	492	18,828	9.65	3.23	66

* Noon to noon.

† Pounds per ton of beets processed.

ton of processed beets, indicating 65 per cent B.O.D. removal on a pounds-per-ton-of-beets basis.

pH

The range of pH at the various stations indicated that carbon dioxide quickly eliminated monocarbonate (phenolphthalein alkalinity) present in the raw waste, and that algal actions in the lagoons were incapable of monocarbonate restoration, which is usually associated with dense algal populations. In all instances except one, field and effluent pH measurements indicated the presence of free carbon dioxide (range 7.0 to 7.9).

Alkalinity

Phenolphthalein alkalinity occurred only in the raw waste, and in only one of three composites. Total alkalinity of the raw waste averaged 1,807 p.p.m. and the effluent average was 557 p.p.m., a reduction of 69 per cent. Section II afforded greater reduction than Section I, but was not as efficient as Section III in this respect. The lowest alkalinities occurred in the effluent from the uppermost lagoon, yet there was a progressive increase in the second and third ponds. This occurrence was contrary to what is usually expected from lagoons in series. The major portion of alkalinity removal on the disposal area apparently resulted from sedimentation in the upper region.

Nitrogen

Ammonia nitrogen was rapidly reduced in all sections of the field, the greatest removal being afforded by flow through the shallow lagoons in Section II. Flow from Sections I and III increased the ammonia content in the effluent from Section II, but the field afforded 94.3 per cent removal (3.5 to 0.2 p.p.m.). Nitrite was present only in the raw waste.

Phosphate

Phosphate varied according to the location, being 5.0 p.p.m. in the raw waste, the effluent, and the discharge from Section III, 7.0 p.p.m. at the end of Section I, and 3.0 p.p.m. in the water leaving Section II. Two series of samples indicated identical conditions and no reduction of phosphate on the disposal area.

Biological Features

Coliform-Type Bacteria

Coliforms usually exhibited an increase in all areas of the field except in Section I, where their concentration (median M.P.N. 9,300,000) was normally below that of the raw waste (median M.P.N. 15,000,000). Median M.P.N. of the effluent was 24,000,000. Coliform increase on the disposal area may possibly represent aftergrowth of those occurring in the raw waste, or augmentation by the leaching of cattle manure. The field's tendency to increase coliform-type bacteria is con-

trary to the results obtained in 1953. Algal growths in Section II were apparently insufficiently concentrated to afford a depression of coliforms.

Plankton

As in 1953, the bulk of the phytoplankton growth consisted of *Chlamydomonas* sp. Rare phytoplankters were the diatoms *Navicula* sp. and *Nitzschia* sp., the green alga *Chlorella*, and the euglenophytes *Euglena* sp. and *Phacus* sp. Zooplankters consisted of the ciliate protozoans *Paramecium, Metopus,* and *Opisthonecta.*

Suspended algae attained sufficient development to impart a green color to the water only in the three lagoons and in a small quiescent area near the northwest corner of Section I (Point A, Figure 1). Algal development was not uniform in all areas of the lagoons. The greatest concentration noted (307,680 organisms per milliliter) was near the southwest corner of the upper lagoon on October 27. The density at that point was more than twice as great as in the lagoon overflow at the southeast corner. The second and third lagoons exhibited almost identical algal concentrations (94,000 per milliliter) on October 27, but the concentration was considerably greater in the third lagoon on October 25. No algae were observed growing attached to grasses in any area; the main paths of flow, in which algae occurred attached to sewage fungus (*Sphaerotilus*) filaments in 1953, contained only fungi in 1955. Lower areas of the field, which contained algae in widespread areas in 1953, were devoid of such growths in 1955. Algal concentration in the plankton was not as great as noted in certain small areas in 1953, and the effluent concentration was only 1,380 per milliliter as compared with 66,500 per milliliter in 1953.

A mixture of flows from all three sections of the upper field should have given an algal concentration of 35,668 organisms per milliliter in the effluent on October 27, yet only 1,380 appeared. Die-off in the lower portion of the field gave sparse populations in regions where dense accumulations were present in 1953.

Other Biological Features

Bottom dwelling and other aquatic insects were found only in the marshy area (Point B) in Section III. Water native to that area had been replaced by beet wastes and some of the insects (mayfly nymphs) exhibited signs of distress. Snails also appeared to be adversely affected. In addition to mayflies (*Ameletus* sp.) the area contained mosquito larvae (*Culiseta impatiens*), soldier fly larvae (*Odontomyia cincta*), dragon fly nymphs (*Anax junius* and *Tarnetrum* sp.), water scavenger beetles (Hydrophilidae), and water boatmen (*Sigara alternata*). Snails were *Lymnaea palustris* and *Lymnaea abrussa.*

Sewage fungus (*Sphaerotilus*) formed long gray streamers that were most numerous attached to grass and other vegetation in currents traversing Sections I and III and in the lower region receiving flows from all three sections. The fungus did not occur in the lagoons or in their discharges.

Discussion

Comparison of the 1953 and 1955 operation and survey results shows that:

1. A greater waste load was applied to the field in 1955.
2. Fewer pounds of B.O.D. reached the receiving stream in 1955.
3. A greater percentage reduction of the B.O.D. concentration in wastes applied to the field was effected in 1953.
4. Suspended solids removal was greater in 1955.
5. Coliforms were reduced by 89 per cent in 1953, but they increased on the field in 1955.
6. Time required for introduced wastes to reach the outlet was in-

creased by 13.5 hr. in 1955, and retention in the lagoon areas was at least 11.5 hr. greater than the total time of passage in 1953.

7. Algal growths were much more widespread and their concentration greater in 1953.

Operation in 1955 showed considerable improvement over 1953 in the matters of waste distribution and retention, yet B.O.D. concentration was reduced to a lesser extent and coliform-type bacteria increased their numbers on the field. The larger waste load applied to the disposal area in 1955 does not appear to be the cause of the lower efficiency, as longer retention would be expected to compensate for the increase.

Experience with algal effects on B.O.D. and coliform-type bacteria in the raw sewage lagoons indicates that the reduced efficiency in 1955 resulted from a lesser growth of algae. In 1953 algae blanketed large regions of the field, and had much greater concentration than they exhibited in the small acreage to which they were restricted in 1955. In sewage lagoons, coliform-type bacteria show limited survival in the algal-laden medium and B.O.D. is substantially reduced. In 1953 significant algal concentrations occurred downfield from the 450-ft. point and their presence offers the most likely explanation for the coliform reduction and the greater B.O.D. removal.

The factors responsible for a lesser algal growth in 1955 are unknown, but it would appear that climatological conditions are more suspect than the minor changes in waste composition.

The higher degree of wastes removal afforded by the lagooned section substantiates the validity of the 1953 recommendation advising grading and diking to promote uniform flow and greater retention time. The lagoons provided in 1955 were inadequate to truly demonstrate their potential, because bottom irregularities, particularly in the second and third units, prevented optimum retention. Nonuniform flow across the dams augmented the short-circuiting inherent in the uneven bottoms. Wind action will remain an important factor in flow patterns over the long corrugated metal dikes. However, with these shortcomings, retention time was sufficient to allow algal growths to markedly affect various waste components. Provision of lagoons with bottoms sufficiently graded to give uniform water coverage would enhance the waste treatment. Increased depth of lagoons 2 and 3 might have been advantageous. Parallel series of graded lagoons extending about 2,000 ft. downfield, and covering the entire field area down to that point, could be expected to produce an effluent of considerably higher quality. Grading and diking of the entire area, as recommended in the 1953 report, in all probability would have similar effects.

Use of shallow lagoons appears to permit equivalent waste reduction with less area than has been observed for "grassland" treatment. This may be important at refineries where suitable land is not available or is exorbitantly expensive.

Summary

The Bayard, Nebr., land disposal area for treatment of sugar beet wastes was modified in certain respects according to recommendations arising from a study of its efficiency in 1953. A joint study to evaluate benefits of the improvements was initiated October 20, 1955, by the Great Western Sugar Company, owner of the facility, the Nebraska State Department of Health, the Wyoming Department of Public Health, and the U. S. Public Health Service.

The distribution system was improved by installation of metal-lined header and distributor flumes. Dikes, whose washouts often permitted bypasses in 1953, were elevated and com-

pacted. Three shallow lagoons, each with an area of 5.3 acres, were constructed in a series extending 1,500 ft. down the center of the upper field. Pulp screen and pulp press water, formerly discharged directly to a drain ditch, were connected to lines leading to the disposal area. Beet tailings water and drainage from coal storage and drippage pits were the only wastes not disposed to the land area.

Wastes were uniformly distributed across the upper end of the field and retention time was increased by 11.5 hr. (25 hr. in the lagooned area). Purification accomplished included virtually complete removal of suspended solids, a 55-per cent reduction in B.O.D. concentration, a 63 per cent removal in pounds of B.O.D. applied to the field, an alkalinity reduction of 69 per cent, complete elimination of nitrite nitrogen, and a 94.3-per cent removal of ammonia nitrogen. Coliform-type bacteria increased their concentration on the disposal field and phosphates were not affected.

The average daily B.O.D. load was 18,560 lb.; the daily removal was 12,127 lb. Each ton of processed beets discharged 9.7 lb. of B.O.D. to the field and the effluent contained 3.36 lb. per ton.

Average discharge was 7.1 c.f.s. for the raw waste and 5.45 c.f.s. for the field effluent. Water loss on the field was 3.27 acre-ft. per day. Evaporation loss was estimated at 0.18 acre-ft., which indicated a 3.09 acre-ft. loss to infiltration.

The lagoons provided greater removal of B.O.D., nitrogen compounds, and alkalinity than did other areas of the field. They also reduced the phosphate concentration, but their influence in that respect was so overcome by flows from other areas that the effluent phosphate level was identical to that of the raw waste.

Acknowledgments

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References

1. Porges, R., and Hopkins, G. J., "Broad Field Disposal of Sugar Beet Wastes." THIS JOURNAL, **27**, 1160 (1955).
2. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).

BIOLOGICAL OXIDATION OF OIL REFINERY WASTES IN COOLING TOWER SYSTEMS*

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Biological oxidation of effluent waters has become an established process in oil refinery practice in recent years. Several commercial-scale activated sludge and trickling filter units have been installed for organic waste reduction by various refiners since 1953. This equipment has operated successfully, proving the applicability of bacterial oxidation to refinery effluents containing phenols and other oxygen-consuming contaminants.

Coincident with the need for improved quality of refinery effluent waters to prevent pollution of receiving streams has been the growing requirement for new water supplies to satisfy the increased demands of industrial expansion. The shortage of existing water supply facilities has led refiners to develop new sources and in some cases to treat waste waters for re-use within the refinery to reduce requirements from external sources. Until recently the need for costly intermediate treatment procedures has been a deterrent to the application of additional re-use procedures.

A new method of utilizing waste waters has been developed that does not require extensive pretreatment and achieves pollution reduction of the over-all effluent. This dual benefit is accomplished by selective segregation of waste waters at their source, simple gravity separation of oil and settleable solids in conventional API separators, four to five days retention in an impounding basin for equalizing the flow, and then biological oxidation in refinery cooling towers. The use of cooling tower systems for bacterial oxidation represents a departure from the conventionally used trickling filter or activated sludge equipment.

Waste Disposal and Re-Use System

Biological oxidation of waste waters in cooling tower systems has been employed in the Toledo, Ohio, refinery of the Sun Oil Company. Following a 5-year period of design and construction a new process revision to the refinery's water supply and waste disposal system has been completed. The new facility embodies comprehensive pollution control of all refinery waste waters, extensive re-use of waters within the refinery with minimum pretreatment and a virtually unlimited water supply for emergency fire protection. The need for installing new water supply lines and treatment facilities or purchasing increased quantities of municipal water has been eliminated.

Cooling towers were selected as the equipment to utilize the "re-use" waters primarily because of their high volume demand and their potential ability to serve as treatment units for biological oxidation of pollutants in the waste waters. Effective oxidation of phenolic compounds and reduction of chemical oxygen demand in conventional cooling towers would obviate the need for extensive waste treatment equipment for improvement of the final effluent. Cooling towers also have the advantage of requiring a relatively low quality make-up water, compared with other process equipment, thereby

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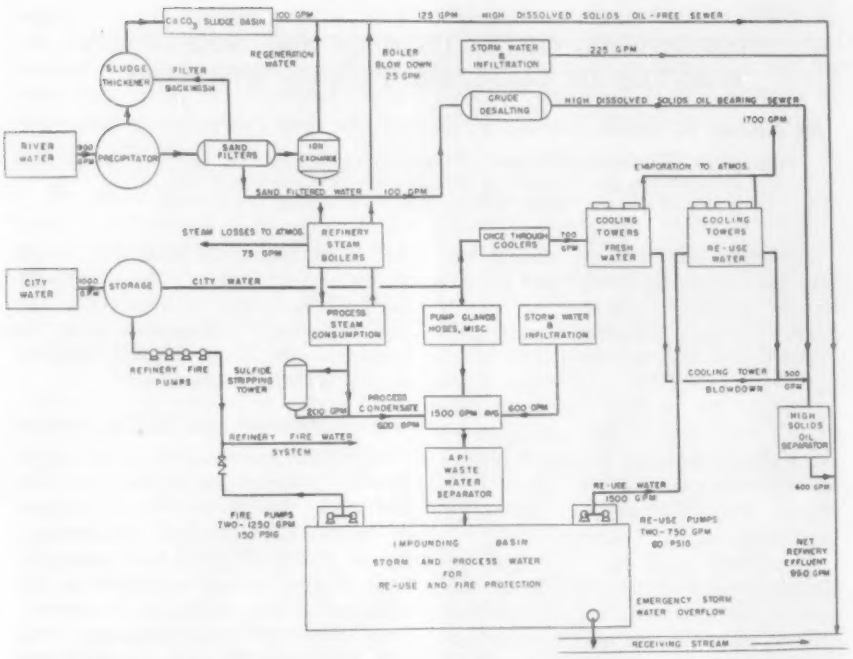

FIGURE 1.—Flow diagram of "re-use" water system, Sun Oil Company, Toledo, Ohio.

eliminating costly pretreatment of the water re-used. Furthermore, the towers would reduce by evaporation during recirculation the over-all quantity of waste discharge.

Installing the Re-Use System

Figure 1 is a flow diagram showing the segregation of the various classes of waste waters, the collection, storage, and re-use of the effluent and the quantities involved. The indicated flow rates represent the calculated theoretical water balance for the refinery when the entire system is placed in operation.

The first step in the program was the installation of a flue gas stripping tower to remove sulfides and mercaptans in the process waste waters. These sulfur compounds would be undesirable contaminants in the re-use supply since they could reduce the efficiency of biological oxidation and could be corrosive to tubular equipment used in the cooling system. Approximately 200 g.p.m. of process waters containing sulfides and mercaptans are fed to a 5-ft. diameter by 31 ft. vertical stripping tower packed with Raschig rings. A flow of 120,000 cu. ft. per hour of 950° F. flue gas from a catalytic cracking regenerator is passed through the stripper for sulfide removal. Temperature in the tower is maintained at approximately 190° F. Recently, sulfuric acid has been used for pH adjustment and better stripping. This unit has performed efficiently and maintained a satisfactory quality in the subsequent re-use system.

The second phase of the project consisted of completely segregating refinery waste waters according to chemical characteristics. Low alkalinity process waste waters from such operations as steam stripping, once-through cooling of pump bearings, and miscellaneous

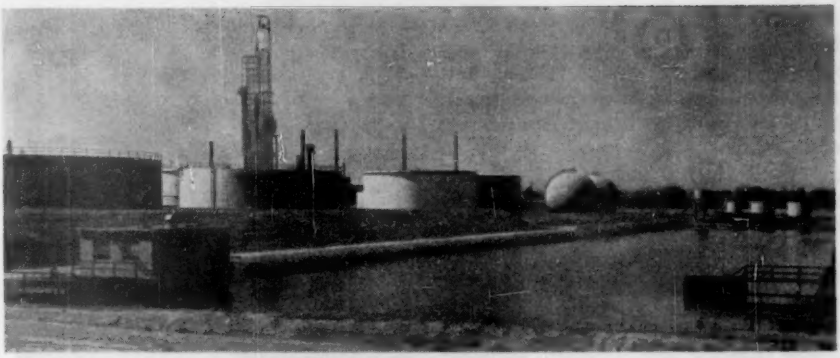

FIGURE 2.—Impounding basin.

wash waters, together with contaminated storm water from ground runoff, flow through the existing refinery drainage system to the API separator for primary removal of oil and settleable solids.

An impounding basin, 1,200 ft. long by 200 ft. wide and 10 ft. deep, with a maximum liquid capacity of 8,000,000 gal., was constructed at the outlet end of the API separator to provide four to five days storage, flow equalization, removal of residual free oil and settleable solids, and preliminary reduction of chemical and biochemical oxygen demand. A minimum of 1,500,000 gal. of waste water is reserved in the impounding basin to provide an emergency fire water supply for not less than 10 hr. A ground level view of the impounding basin is shown in Figure 2.

Oil-free waste waters, high in alkalinity and not suitable for re-use, including ion exchange regeneration water from the water plant and blowdown from steam boilers, are collected and sewered directly to the receiving stream. Oil-bearing, high alkalinity waste waters, including cooling tower blowdown and crude desalting wash water, are segregated in a new sewer system and delivered to an auxiliary API high-solids separator for oil removal before discharge. The main quantity of refinery waste waters is collected in the low alkalinity re-use sewer and impounding basin system. Two 750-g.p.m. pumps were installed at the impounding basin to return process and storm water to the existing refinery cooling towers for make-up water. No treatment except gravity separation and impounding has been required prior to re-use of this water. Additional details of the over-all installation were presented in another paper (1).

Re-use Operation

In November 1954, the first re-use of waste water was started at the Toledo Refinery. One pump was operated to return 600 g.p.m. of waste water to the main return line of a large forced draft cooling tower. This tower cools circulating water for conventional condensers and coolers in a catalytic cracking plant.

Within a few hours after the start-up of re-use operation, there was evidence of a good bacterial floc in the system. Bacterial seed was not necessary to initiate the growth of an active colony of bacteria. The phenol content of the blowdown water from this system was reduced more than 99 per cent. From the initial data, it has been proven that the active bacterial sludge contained phenol-oxidizing microorganisms. These bacteria are apparently both water- and air-borne.

Examination of the bacterial sludge by means of the optical and electron microscopes has shown the presence of rod-shaped bacilli and circular cocci, and bacterial identification studies are now in progress. Previous investigators (2) have indicated that such genera as *Achromobacter* and *Micrococcus* are effective phenol oxidizers.

In this type of biological oxidation, the microorganisms present are heterotrophic bacteria which depend on organic compounds as a source of energy. These bacteria are classified as mesophilic since their optimum activity is in a temperature range of 60° to 100° F.

According to Rudolfs (3) the destruction of aromatic compounds by biological oxidation is initiated by oxidation of the side chain and this is followed by the splitting of the nuclear ring and subsequent oxidation. The end products of the reaction are carbon dioxide and water.

The rate of destruction of phenolic-type compounds is dependent upon several variables, including the types of compounds, the concentration of the compounds, the temperature of the water, the availability of auxiliary nutrients such as nitrogen and phosphorus compounds, and the presence in the system of microfauna and microflora.

TABLE I.—Cooling Tower Operating Data

Item	Detail
Type	Forced draft
Number of cells	16
Cell dimensions (ft.):	
Width	30
Length	16
Height	24
Fans	12-ft., 4-blade plastic, one per cell
Water rates (g.p.m.):	
Circulating	17,500
Make-up	600–1,000
Blowdown	100–500
Air rate (c.f.m.)	3,000,000
Air-water ratio	1.58
Temperatures (° F.):	
Water inlet	83 to 98
Water outlet	64 to 80

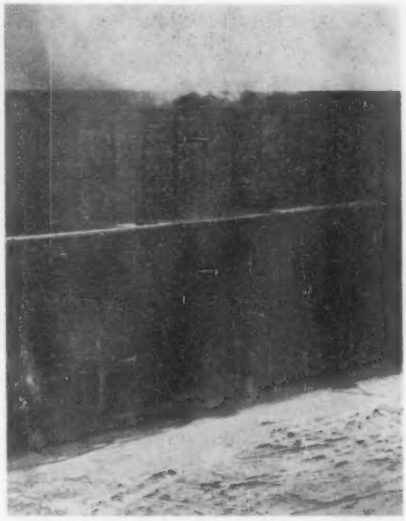

FIGURE 3.—Typical elevation view of a forced draft cooling tower.

The data presented in Table I shows that the forced draft cooling tower (Figure 3) offers exceptionally good physical conditions for biological oxidation by providing extensive internal contact surfaces. The dilution factor ranges from 17 to 29, and this prevents any shock to the established biological equilibrium when large variations are encountered in the phenol load of the make-up water. An ample supply of available oxygen is insured by the air to water weight ratio of 1.58. A temperature range of 64° to 98° F. is conducive to a high rate of bacterial growth.

Ammonium compounds are present in the phenolic make-up water and serve as nutrients for the growth of the bacteria. Phosphates are added to the circulating cooling water to improve the food balance and establish a high degree of bacterial activity. This biologieal oxidation process functions with a light bacterial floc circulating from the cooling tower through all of the plant cooling equipment before re-

TABLE II.—Phenol Removal Efficiency in a Forced Draft Cooling Tower

Date	Sample Location	Flow			Phenols				Operation
		(g.p.m.)	(m.g.d.)	(million lb. per day)	(p.p.m.)	(lb./day)	Removal (lb./day)	Removal (%)	
1954									
Dec. 16	Make-up	600	0.865	7.210	18.4	133	—	—	
	Blowdown	100	0.144	1.198	0.194	0.23	132.8	99.8	*
Dec. 29	Make-up	565	0.815	6.790	15.7	107	—	—	
	Blowdown	100	0.144	1.198	0.211	0.25	106.8	99.8	*
1955									
Feb. 23	Make-up	1,100	1.590	13.250	8.6	114	—	—	
	Blowdown	600	0.875	7.280	0.167	1.2	112.8	98.9	†
Mar. 22	Make-up	1,100	1.590	13.250	12.7	169	—	—	
	Blowdown	600	0.875	7.280	0.208	1.5	167.5	99.2	‡
Mar. 24	Make-up	1,185	1.706	14.220	12.7	181	—	—	
	Blowdown	600	0.875	7.290	0.324	2.4	178.6	98.7	‡
Nov. 7	Make-up	600	0.865	7.210	19.6	141	—	—	
	Blowdown	100	0.144	1.198	0.800	0.96	140	99.4	§
Nov. 11	Make-up	600	0.865	7.210	48.0	346	—	—	
	Blowdown	100	0.144	1.198	0.082	0.099	345.9	99.9	§
Dec. 8	Make-up	600	0.865	7.210	43	310	—	—	
	Blowdown	100	0.144	1.198	0.055	0.066	309.9	99.9	§
Dec. 29	Make-up	600	0.865	7.210	53.5	386	—	—	
	Blowdown	100	0.144	1.198	0.016	0.019	385.98	99.9	§
1956									
Feb. 7	Make-up	1,000	1.440	12.000	70.0	840	—	—	
	Blowdown	500	0.720	6.000	0.41	2.46	837.5	99.7	‖
Feb. 16	Make-up	1,000	1.440	12.000	25.6	307	—	—	
	Blowdown	500	0.720	6.000	0.052	0.31	306.7	99.9	‖

* 2.1 cycles of concentration. Phenolic water from Houdry fixed-bed unit.
† 1.2 cycles of concentration. Phenolic water from Houdry fixed-bed unit.
‡ 1.2 cycles of concentration. Phenolic waters from Houdry fixed-bed and Houdriflow units.
§ 2.1 cycles of concentration. Phenolic waters from two Houdriflow units.
‖ 1.2 cycles of concentration. Phenolic waters from two Houdriflow units.

turning to the tower. This system combines the high-rate trickling filter and recirculating sludge processes into one highly effective waste treatment installation.

Comprehensive data on the phenol removal efficiency of the re-use water operation are listed in Table II. The average reduction exceeded 99 per cent under widely variable concentrations of phenol and fluctuating refinery operating conditions.

When the success of the first phase of operation was established, the second re-use pump was placed in service to determine the performance of the biological oxidation under approximately double the initial load. No perceptible loss in efficiency was noted even after process waters from two Houdriflow catalytic cracking plants were included in the make-up water.

A peak phenol loading occurred on February 7, 1956. At this time, 840 lb. per day of phenolic compounds were fed to the cooling tower. Only 2.5 lb. per day of phenols were discharged in the oxidized blowdown water. The per cent of removal was 99.7 under these conditions.

Chemical oxygen demand efficiency data are summarized in Table III. The first section of the table includes results obtained during periods when the cooling tower was receiving a make-up water supply of 600 g.p.m. The daily quantities of C.O.D. present in the make-up water varied between

TABLE III.—Chemical Oxygen Demand Removal Efficiency in a Forced Draft Cooling Tower

Date	Sample Location	Chemical Oxygen Demand				Operation
		(p.p.m.)	(lb./day)	Removal (lb./day)	Removal (%)	
1955						
Nov. 3	Make-up	280	2,020	—	—	
	Blowdown	188	225	1,795	88.9	
11	Make-up	463	3,340	—	—	
	Blowdown	285	341	2,999	89.8	
22	Make-up	331	2,390	—	—	
	Blowdown	141	169	2,221	93.1	
Dec. 6	Make-up	541	3,905	—	—	2.1 cycles of concentration.
	Blowdown	369	442	3,463	88.8	Phenolic waters from two
13	Make-up	389	2,802	—	—	Houdriflow units, 600 g.p.m.
	Blowdown	194	232	2,570	91.8	make-up water, and 100
21	Make-up	536	3,860	—	—	g.p.m. blowdown waste.
	Blowdown	344	412	3,448	89.4	
29	Make-up	441	3,178	—	—	
	Blowdown	369	442	2,736	86.1	
1956						
Jan. 4	Make-up	304	2,190	—	—	
	Blowdown	196	235	1,955	89.4	
11	Make-up	199	1,435	—	—	
	Blowdown	168	201	1,234	86.1	
Feb. 1	Make-up	227	2,725	—	—	
	Blowdown	152	912	1,813	66.5	
7	Make-up	303	3,630	—	—	
	Blowdown	237	1,420	2,210	60.8	1.2 cycles of concentration.
17	Make-up	233	2,790	—	—	Phenolic waters from two
	Blowdown	133	798	1,992	71.4	Houdriflow units, 1,000
23	Make-up	301	3,610	—	—	g.p.m. make-up water, and
	Blowdown	142	850	2,760	76.3	500 g.p.m. blowdown waste.
28	Make-up	266	3,190	—	—	
	Blowdown	165	990	2,200	69.0	
Apr. 4	Make-up	368	4,420	—	—	
	Blowdown	263	1,580	2,840	64.3	

1,435 and 3,860 lb., with an average reduction of 89 per cent.

The second set of data in Table III illustrates the C.O.D. reduction attained when both re-use water pumps were operated. In considering the results, it appears that a loss in efficiency is encountered when the blowdown rate is increased. The average C.O.D. removal was 68 per cent under these conditions. Present operation is based on a minimum blowdown rate so that the optimum oxygen demand is satisfied.

A complete program for evaluating this system included frequent chemical control tests for all significant components in the make-up and circulating water.

From the standpoint of quality, the high alkalinity of the make-up water is undesirable. Concentrated sulfuric acid is added to the circulating cooling water to depress the alkalinity to approximately 100 p.p.m. as calcium carbonate. Because the bacteria produce carbon dioxide as an end product in the destruction of organic compounds, appreciable acidity is contributed; therefore sulfuric acid consumption is correspondingly decreased below the stoichiometric demand.

Sodium polyphosphate is fed into the cooling water three times each day.

TABLE IV.—Chemical Quality of Cooling Tower Re-use Water

	Cooling Tower Make-up			Cooling Tower Blowdown		
	Max.	Min.	Avg.	Max.	Min.	Avg.
pH	9.15	6.75	8.20	7.85	6.50	7.25
Alkalinity, as $CaCO_3$ (p.p.m.)	284	68	163	160	52	93
Sulfates, as $CaSO_4$ (p.p.m.)	431	193	286	645	212	436
Iron (total), as Fe (p.p.m.)	3.38	0.57	1.19	3.84	0.63	1.68
Copper (total), as Cu (p.p.m.)	4.90	0.18	0.75	5.76	0.28	1.31
Suspended solids (p.p.m.)	57	10	28	164	24	72
Dissolved solids (p.p.m.)	678	336	501	1,000	397	684
Nitrogen (basic), as NH_3 (p.p.m.)	124	53	80	132	39	81
Phenolic compounds, as phenol (p.p.m.)*	74.0	8.4	25.9	1.20	0.004	0.092
C.O.D. (p.p.m.)	541	172	327	436	141	231
B.O.D. (p.p.m.)	259	82	158	208	67	111

* Phenolic compounds determined by the 4-aminoantipyrine method.

This surface-active agent is considered beneficial in controlling corrosion and scale deposition in the refinery boilers. As previously mentioned, phosphates also are very essential nutrients in the biological oxidation process.

The bacterial floc accounts for almost all of the suspended solids in the circulating water. Although most of the operation was carried out with 2.1 cycles of concentration based on chloride content of the make-up and circulating water, the average dissolved solids content shows only a slight increase in the recirculating cooling water system. This trend is a result of biological oxidation and the volatilization of certain compounds from the cooling tower. Since a problem of excessive concentration is avoided, the tower requires only a small blowdown rate.

At times, appreciable concentrations of copper are noted in the circulating water. No decrease in the activity of the bacteria has been detected in spite of these surges of copper. A recent publication (4) stated that phenol-consuming bacteria can tolerate up to 100 p.p.m. of copper.

Approximately 50 per cent of the ammonia is consumed in the biological oxidation system. It is believed that the ammonia content is quite important in the preservation of a good level of metabolic activity. Other pertinent chemical data are included in Table IV.

Operating Effects

Sludge and Algae

The possible detrimental effect of the bacterial sludge on heat transfer in the refinery cooling equipment was a subject of some concern. A program of backwashing all condensers and coolers once each shift was inaugurated at the time water re-use was started. The fluid characteristics of the bacterial sludge gave a reasonable assurance that backwashing could prevent fouling of the boiler tubes.

During the first few weeks of water re-use operation, a weekly shock treatment of chlorine was used as added insurance against a reduction in heat transfer efficiency. This treatment was discontinued after six weeks and no build-up of bacterial growths has been encountered.

Periodic surveys before and after initiating the re-use system show a consistent heat treatment coefficient of 50 Btu. per square foot per hour per degree Fahrenheit. It is planned to continue this program of checking plant units on a routine basis.

No objectionable algae or slime growths have been detected in this

TABLE V.—Corrosion Rate Data—Re-use Cooling Water System

Metal	Date	Water Temp. (° F.)	Corrosion Rate	
			Inches/Year	Milligrams/Sq. Decimeter/Day
Steel	1955			
	Jan. 13–Feb. 11	90	0.005	27
	Jan. 13–Feb. 11	130	0.005	27
	Feb. 23–Mar. 17	90	0.003	16
	Feb. 23–Mar. 17	130	0.005	27
	1956			
	Jan. 6–Apr. 23	90	0.007	45
	Jan. 6–Apr. 23	130	0.004	25
Brass	1954			
	Nov. 26–Dec. 9	90	0.004	25
	Dec. 10, '54–Feb. 11, '55	90	0.002	14
	1955			
	Jan. 13–Feb. 11	90	0.006	30
	Feb. 16–Mar. 17	90	0.006	30
	Feb. 23–Mar. 23	90	0.003	19
	Nov. 1, '55–Apr. 23, '56	90	0.001	8

cooling water system since the start of biological oxidation. The phenol-destroying bacteria are believed to consume algae and thus exert a strong controlling influence in curbing such conditions.

Corrosion

The last major investigation was concerned with the study of corrosion rates in the re-use water system. Miniature heat exchangers were installed so that frequent observations could be made to determine the condition of the brass and steel tubes. In addition, two new flanged elbows were placed in service so that line thickness measurements and inspection data could be secured during scheduled shutdowns.

Thus far no tuberculation or pitting of steel has been evident. The dissolved organic wastes in the re-use water exert a high oxygen demand in the water pumped from the cooling tower to the plant tubular equipment and probably serve to control some of the corrosive tendencies usually exhibited by oxygen-saturated cooling water.

Table V includes corrosion rate data for steel and brass tubes. The average rate for steel was 0.005 in. per year, whereas that for brass was 0.0035 in. per year. These measured corrosion rates are at essentially the same low levels as previously observed when fresh water make-up was used.

Examination of wood specimens obtained from the 18-year old cooling tower, after four months of water re-use operation, disclosed no evidence of biological deterioration. Additional periodic inspections are planned, including checks on fresh-wood specimens.

Conclusions

Biological oxidation of refinery waste waters in cooling tower equipment represents a highly efficient and economical treatment process. This practical method for pollution reduction offers an attractive alternative to conventional trickling filter or activated sludge methods. Selective segregation of process wastes at their source and elimination of undesirable constituents such as oil, sulfur compounds, alkalinity and settleable solids must be accomplished before re-use streams are fed

to cooling towers in order to maintain satisfactory quality of the circulating water.

Extending waste segregation, storage, and water re-use to the entire refinery provides an integrated system for pollution control, water conservation, and emergency fire protection.

Acknowledgments

The authors are most appreciative of the cooperation from the operating supervision of the Toledo Refinery.

References

1. Elkin, H. F., "Biological Oxidation and Re-Use of Refinery Waste Water for Pollution Control." *Proc. Amer. Petroleum Inst.* (May, 1956).
2. Lynn, G. E., and Powers, T. J., "Bacterial Studies in Oxidation of Phenolic Wastes." THIS JOURNAL, **27**, 1, 61 (Jan., 1955).
3. Rudolfs, W., "Industrial Wastes." Monograph No. 118, Amer. Chem. Soc., New York, N. Y. (1953).
4. Ross, W. K., and Sheppard, A. A., "Biological Oxidation of Petroleum Phenolic Wastes." Proc. 10th Indus. Waste Conf., Purdue Univ. (1955).

SEWERAGE CONSTRUCTION NEEDS—$22 BILLION

Capital investment to increase public sewerage system facilities and expenditures to offset obsolescence during the next 20 years will total $22.2 billion according to the Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, U. S. Department of Commerce. These expenditures are considered to be necessary to provide adequate service in collection and treatment of sewage from the expanding population of the United States. Needs of the projected program for 1955–75, in billions of 1954 dollars, are summarized as follows:

To eliminate present deficiencies	$5.8
For growth in population and water use	8.3
To offset obsolescence and depreciation	8.1
Total	$22.2

Present replacement cost of public sewerage facilities in 1954 dollars is estimated at $19.9 billion. Required capital outlays would increase this investment to $34 billion by the end of 1975.

Many inadequacies exist, particularly in the need to improve sewage treatment facilities to meet present stream sanitation standards. An estimated expenditure of $5.8 billion is necessary. Further expenditure of 8.3 billion will be required during the 20-year period to keep the public facilities abreast of population growth and increased rate of water usage. To keep all treatment facilities adequate, continuing expenditures totaling 8.1 billion in 20 years is considered essential.

Principal factor affecting the expenditures is the increase in population residing in the United States from about 164.6 million persons in 1955 to 206.6 million in 1957. The population estimated to be served by public sewerage systems in 1975 is expected to approximate 134 million—an increase of 34 million over 1955.

THE MICROBIAL OXIDATION OF PURE CARBOHYDRATE IN THE PRESENCE OF CALCIUM LIGNOSULFONATE

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The rate of oxidation of carbohydrates by microorganisms has been studied by numerous investigators. However, there appear to be no known references in the literature relating to the microbial oxidation of pure carbohydrate in the presence of "pure" calcium lignosulfonate. The Green Bay Report (1) contains some data on the biological oxygen demand of a sample of calcium lignosulfonate, but no reference to any work done with the calcium lignosulfonate and carbohydrates.

The discharge of spent sulfite liquor into a stream causes an early oxygen demand due chiefly to the carbohydrate content of the liquor. As the water flows downstream, the microbial activity rapidly reduces the concentration of carbohydrate, although there is only a very small decrease in the calcium lignosulfonate present due to its relative inertness to attack by microorganisms.

The influence of calcium lignosulfonate on the microbial oxidation rate of carbohydrate and the determination of the effect, if any, of a change in the ratio of calcium lignosulfonate to carbohydrate were the subjects of the investigation reported herein. The hexoses investigated, such as glucose, mannose and galactose, were those known to be present in spent sulfite liquor. The pentoses, arabinose, and xylose were included for purposes of comparison and because xylose is undoubtedly present in the spent liquor.

The Androscoggin River water has continuously received spent sulfite liquor for more than 50 years. Accordingly, its waters were used for the innoculations.

Spent Sulfite Liquor

The composition of spent sulfite liquor varies not only with the kind of wood employed but with the temperature, time of cook, and the concentrations of sulfite. The assumption has been made that the average composition of the liquor would be approximately as follows:

Component		Percentage
Lignin*		4.5
Carbohydrate		2.5
Glucose	50	
Mannose	15	
Galactose	8	2.5
Pentosans	27	

* The term lignin has been used to denote calcium lignosulfonate.

Laboratory Procedure

The carbohydrates were the purest available and every precaution was taken to avoid contamination after the containers had been opened. The calcium lignosulfonate used was a light buff colored powder prepared by precipitation and dialysis. The empirical formula was assumed to be $C_{43}H_{42}O_{14}$ and the molecular weight 782. Both assumptions ignore the calcium sulfonate radicle.

Sterilized aerated distilled water was fortified with salts as recommended by Lee and Nichols. The concentrations employed were:

Ammonium sulfate (p.p.m.)	2.5
Calcium phosphate (p.p.m.)	0.01
Potassium dihydrogen phosphate (p.p.m.)	0.05
Magnesium sulfate, crystal (p.p.m.)	0.01

Inoculations were made by adding 2 ml. of Androscoggin River water to each B.O.D. bottle. The pH was 6.5 and all incubations were conducted at 20° C. The incubation periods were usually 2, 5, 7, 10 and 15 days. Occasionally 20- and 30-day periods were investigated, but usually the results were very erratic.

Analyses were made by the procedures given in *Standard Methods* (2). The hypochlorite modification was used for the dissolved oxygen determinations. The Spectronic 20 colorimeter was used for the determinations of calcium lignosulfonate, using sodium tungstate-phosphomolybdic reagent. It was assumed that the wood used for sulfite pulp averages approximately 30 per cent calcium lignosulfonate.

General Observations

The microorganisms obtained from the river water required a few days to acclimatize themselves to pure carbohydrate alone or a mixture of pure carbohydrate and "pure" calcium lignosulfonate, in Lee and Nichols dilution water. This time lag was independent of the season of the year. Inoculations made with water obtained in the winter reacted the same as when the samples were obtained in the early, mid, or late summer. Inoculations made from stabilized river water yielded the same results as fresh water.

With the exception of galactose, the pure carbohydrate solutions had B.O.D. values which were lower than the calculated ones. Since all the determinations were conducted under comparable conditions, it is probable that the results are also comparable.

Lee and Nichols dilution water is devoid of organic nitrogen compounds. One set of glucose-lignin solution determinations was studied after the addition of 0.1 p.p.m. peptone equivalent to a carbohydrate-peptone ratio of 300 to 1. The considerable increase in microbial activity produced by the peptone was confined principally to the first two days of incubation.

The B.O.D. data from solutions containing carbohydrate-lignin ratios of 1 to 15 or more, were very erratic and inconsistent.

The results of this investigation do not support the contention expressed in the Green Bay Report (1), that the carbohydrate makes possible the microbial production of enzymes which can convert calcium lignosulfonate into compounds which have an appreciable B.O.D.

Calcium Lignosulfonate

The B.O.D. of the sample of calcium lignosulfonate used in this investigation was found to be somewhat higher than that obtained in the Green Bay Studies. The difference in origin, source of organisms, and especially in the method of laboratory sample preparation may account for the lack of agreement. Removal of all carbohydrate from spent sulfite liquor solids is not readily attained. However, data from both series of experiments (Table I) show very definitely that the calcium lignosulfonate had only a small B.O.D.

Whether this demand is the result of the conversion of calcium lignosulfonate into organic compounds avail-

TABLE I.—Comparison of Calcium Lignosulfonate Data

Incubation Period (days)	Lawrance-Fukui Study		Green Bay Report	
	B.O.D. (p.p.m.)	Oxidation (%)	B.O.D. (p.p.m.)	Oxidation (%)
2	16,700	0.88	16,800	0.9
4	55,100	2.9	22,400	1.2
5	60,800	3.2	30,800	1.6
7	68,400	3.6	—	—
9	—	—	35,000	1.8
10	100,000	5.3	—	—
14	—	—	53,300	2.8
15	118,000	6.2	—	—
20	131,000	6.9	—	—
23	—	—	55,000	2.9

TABLE II.—Glucose and Glucose-Calcium Lignosulfonate Mixtures

Item	Incubation Period (days)					
	2	4	5	7	10	15
(*a*) Pure Glucose						
B.O.D. (p.p.m.)	0.22	4.06	13.75	15.51	19.60	24.31
Oxidation (%)	0.69	12.6	42.9	48.3	61.2	75.8
(*b*) Glucose and Calcium Lignosulfonate						
Oxidation:						
Glucose (30 p.p.m.)	0.69	12.6	42.9	48.3	61.2	75.8
Lignin (60 p.p.m.)	0.88	2.9	3.2	3.6	5.3	6.2
Statistical total	1.57	15.5	46.1	51.9	66.5	82.0

able to microorganisms as nutrients, or due to other organic substances which were not removed in the process of purification, cannot, at present, be decided. For the purposes of this investigation, it was assumed that the calcium lignosulfonate in the presence of carbohydrate contributed to the oxygen demand to the same extent as it did in the absence of sugar.

The results of the B.O.D. determinations are stated in terms of 60 p.p.m. so as to approximate concentrations which could be found in certain receiving waters. The ratios of carbohydrate to calcium lignosulfonate were varied to ascertain the effect, if any, of lower concentrations of sugar.

Glucose and Glucose-Calcium Lignosulfonate Solutions

The B.O.D. determinations included pure glucose alone and mixed with calcium lignosulfonate in such proportions that the ratios of carbohydrate to calcium lignosulfonate were 1 to 1, 1 to 2, and 1 to 6. The 1 to 1 ratio, although probably never present in spent sulfite liquor dilutions, was studied to obtain data as to the effect of relatively high concentrations of carbohydrate on the microbial oxidation of calcium lignosulfonate. The results are recorded in Tables II and III, and Figure 1. The per cent oxidized refers only to the carbohydrate present and is obtained by subtracting the calcium lignosulfonate oxygen requirement from the total demand of the lignin-carbohydrate mixture.

In all incubations the microorganisms were slow in adapting themselves to the new environment, and, with few exceptions, required two or three days before giving evidence of much activity. This is the reason the seven-day demands for pure carbohydrate were found to approximate the five-day norm.

In general terms, the calcium lignosulfonate depressed the rate of microbial oxidation of glucose but not uniformly. The 1 to 2 ratio solution was affected less than the other mixtures, and, for all practical purposes, the calcium lignosulfonate should be considered as having exerted little or no influence on the rate of oxidation. The 1 to 6 ratio mixture was slightly more active in the early stages of incubation and less so in the later period. The retardation was most noticeable during the 10- to 15-day period. The rate of oxidation of the 1 to 1 carbohydrate-lignin solution was lower than the other solutions tested. This might be due to the absence or appreciable reduction in the concentration of a

TABLE III.—Glucose-Calcium Lignosulfonate Ratios

Incubation Period (days)	B.O.D. (p.p.m.)			Glucose Oxidation (%)
	Glucose and Lignin	Lignin	Difference	
(*a*) Ratio 1 to 6 (10 p.p.m. to 60 p.p.m.)				
2	2.12	1.00	1.12	10.5
5	6.10	3.70	2.40	22.5
7	9.28	4.10	5.18	48.7
10	12.32	6.08	6.24	58.3
15	13.80	7.10	6.70	63.6
(*b*) Ratio 1 to 2 (30 p.p.m. to 60 p.p.m.)				
2	1.20	1.00	0.20	0.6
4	5.94	3.26	2.68	8.4
5	14.70	3.70	11.00	34.3
7	19.74	4.10	15.64	48.8
10	26.94	6.08	20.86	65.1
15	31.20	7.10	24.10	75.2
(*c*) Ratio 1 to 1 (60 p.p.m. to 60 p.p.m.)				
2	1.76	1.00	0.76	1.2
5	23.60	3.70	19.90	31.0
7	28.88	4.10	24.78	38.4
10	35.20	6.08	29.12	45.4
15	43.80	7.10	36.70	57.1
(*d*) Ratio 1 to 1 (0.1 p.p.m. peptone)				
2	8.70*	1.76†	6.94	400 ‡
5	27.10*	23.60†	3.50	14.9‡
7	28.96*	28.88†	0.08	0 ‡
10	42.50*	35.20†	7.30	20.7‡
15	50.20*	43.80†	6.40	14.7‡

* Glucose, calcium lignosulfonate and peptone.

† Glucose and calcium lignosulfonate.

‡ Oxidation increase, per cent.

critical nutrient, possibly organic nitrogen. To test this, a 1 to 1 solution was fortified with 0.1 p.p.m. of peptone and the oxidation rate was then determined (Table III (*d*)). The additional nutrient stimulated the activity of the organisms, especially during the first few days of incubation, and the carbohydrate oxidation rate approached that of the pure glucose solution.

These data indicate that under these experimental conditions the microbial oxidation of glucose is only slightly affected, if at all, by the presence of calcium lignosulfonate in concentrations six times as large as that of the glucose.

Another series of determinations was made using the "Tyrosine" colorimetric test to measure the change in concentration of calcium lignosulfonate during the microbial oxidation of glucose. Concentration ratios of glucose to lignin were 20 p.p.m. to 60 p.p.m. in Lee and Nichols dilution water. Inoculations were larger than in previous experiments and aeration was employed.

Microbial utilization of calcium lignosulfonate appeared, from the data presented in Table IV, to be very low and confined to the first five days of incubation. The decrease in the calcium lignosulfonate content was of the same order of magnitude as in the earlier investigation. Glucose was oxidized at a somewhat faster rate.

The results of the Tyrosine lignin and B.O.D. tests indicate that there is little microbial oxidation of calcium lignosulfonate even when inoculated with water from a source which has been receiving spent sulfite liquor for more than 50 years.

TABLE IV.—Glucose (20 P.P.M.) to Calcium Lignosulfonate (60 P.P.M.)

Days	B.O.D. (p.p.m.)	Total B.O.D. (p.p.m.)	Calcium Lignosulfonate* (p.p.m.)
1	3.10	3.10	60
2	2.61	5.71	59
3	2.10	7.81	58
4	1.73	9.54	58
5	1.12	10.66	57
6	0.65	11.31	57
8	0.35	11.66	57
10	0.39	12.05	57

* Tyrosine test dilution, 1 to 1.

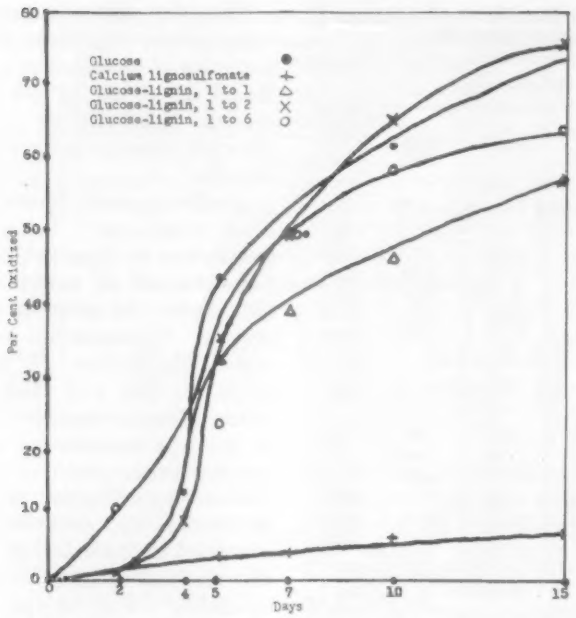

FIGURE 1.—Microbial oxidation of glucose, calcium lignosulfonate and glucose-lignin solutions.

Mannose and Mannose-Calcium Lignosulfonate Solutions

The mannose present in spent sulfite liquor is approximately 15 per cent of the total carbohydrate content.

The solutions studied had mannose-lignin ratios of 1 to 2, 1 to 3, 1 to 6, and 1 to 15. The results of the 1 to 15 ratio were erratic and meaningless and are not included.

An initial lag in activity was experienced similar to that with glucose solutions, but when the microorganisms became adjusted the oxidation proceeded in a more normal way. The calcium lignosulfonate appears to retard the oxidative processes during the first few days and then to mildly stimulate them in the later stages of incubation. However, the stimulation is probably more apparent than real, since the total B.O.D. is not in excess of the calculated requirement for the carbohydrate and calcium lignosulfonate. The data are presented in Tables V and VI, and Figure 2.

TABLE V.—Mannose*

Incubation Period (days)	B.O.D. (p.p.m.)	Oxidation (%)
2	0.88	2.7
5	11.50	35.9
7	13.92	43.4
10	14.80	46.2
15	16.60	51.8

* 30 p.p.m.

Galactose and Galactose-Calcium Lignosulfonate Solutions

The galactose content of spent sulfite liquor is about one-half that of mannose and one-sixth that of glucose. The galactose-lignin ratio is about 1 to 20.

The galactose-lignin solutions which were investigated had ratios 1 to 3,

TABLE VI.—Mannose-Calcium Lignosulfonate Solutions

Incubation Period (days)	B.O.D. (p.p.m.)			Mannose Oxidation (%)
	Mannose and Lignin	Lignin	Difference	
(*a*) Ratio 1 to 6 (10 p.p.m. to 60 p.p.m.)				
2	1.44	1.00	0.44	4.1
5	7.00	3.70	3.30	30.1
7	9.60	4.10	5.50	51.5
10	11.86	6.08	5.78	53.3
15	13.50	7.10	6.40	59.8
(*b*) Ratio 1 to 3 (20 p.p.m. to 60 p.p.m.)				
2	1.64	1.00	0.64	3.1
5	9.01	3.70	5.31	24.9
7	12.40	4.10	8.30	39.0
10	16.02	6.08	9.94	46.7
15	17.60	7.10	10.50	49.3
(*c*) Ratio 1 to 2 (30 p.p.m. to 60 p.p.m.)				
2	1.42	1.00	0.42	1.3
5	17.20	3.70	13.50	42.1
7	19.70	4.10	15.60	48.7
10	23.60	6.08	17.52	54.6
15	24.60	7.10	17.50	54.6

1 to 6, and 1 to 15. The results from solutions with high calcium lignosulfonate content were erratic and, until more data can be obtained, it would be unwise to attempt interpreting them.

After a delay of about two days, the microorganisms became adjusted and the rate of oxidation was quite rapid (Tables VII and VIII, and Figure 3). The actual 5-day B.O.D. values are closer to the calculated values than those obtained for either glucose or mannose. In the 1 to 3 solution, calcium lignosulfonate did not affect the rate of oxidation until after the seventh day when a decrease in activity was observed.

TABLE VII.—Galactose*

Incubation Period (days)	B.O.D. (p.p.m.)	Oxidation (%)
2	0.56	2.6
5	6.10	28.7
7	11.34	53.3
10	17.50	82.2
15	17.60	82.7

* 20 p.p.m.

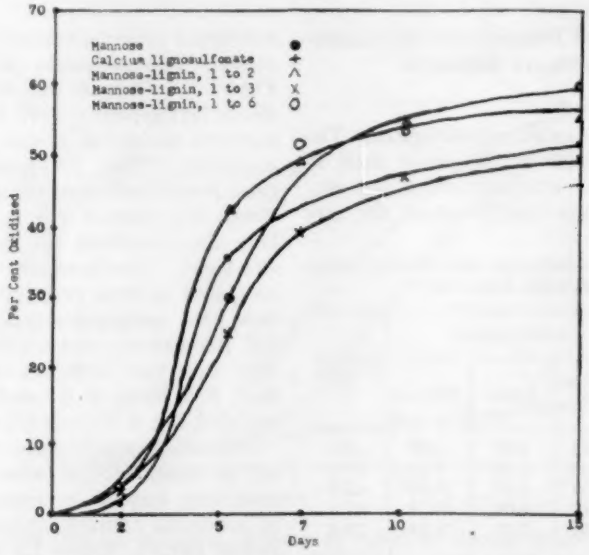

FIGURE 2.—Microbial oxidation of mannose, calcium lignosulfonate and mannose-lignin solutions.

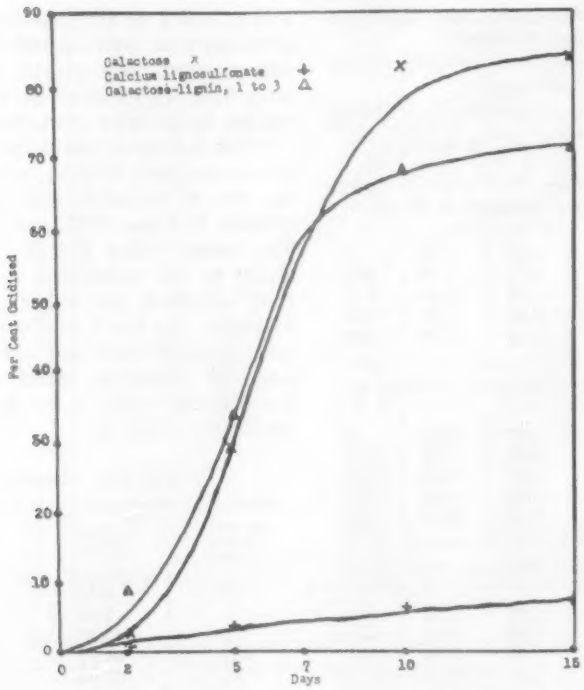

FIGURE 3.—Microbial oxidation of galactose, calcium lignosulfonate and galactose-lignin solutions.

Pentose and Pentose-Calcium Lignosulfonate Solutions

Arabinose

Two pentoses were investigated. The microorganisms in the water used to inoculate the solutions containing arabinose did not readily attack the carbohydrate either alone or mixed with calcium lignosulfonate, as shown in Figure 3. Oxygen was utilized very slowly and approximately 15 days were required to oxidize 50 per cent of the arabinose. The difference between these results and those contained in the Green Bay Report (1) is due to the long time required for microbial acclimation. Furthermore, the organisms used in these two studies may not have been comparable types. The initial populations and nutrients probably were very different in the stabilized Fox River water and in the inoculated Lee & Nichols dilution water.

Calcium lignosulfonate, when present in concentrations twice that of the arabinose, appears to reduce the rate of microbial oxidation throughout the 15-day period (Tables IX and X, and Figure 4).

TABLE VIII.—Galactose and Calcium Lignosulfonate, Ratio 1 to 3*

Incubation Period (days)	B.O.D. (p.p.m.)			Galactose Oxidation (%)
	Galactose and Lignin	Lignin	Difference	
2	2.88	1.00	1.88	8.8
5	10.80	3.70	7.10	33.4
7	17.30	4.10	13.20	63.0
10	20.46	6.08	14.38	67.6
15	22.20	7.10	15.10	70.9

* 20 p.p.m. to 60 p.p.m.

TABLE IX.—Comparison of Arabinose Data

Incubation Period (days)	Lawrance-Fukui Study			Green Bay Report	
	B.O.D.* (p.p.m.)	B.O.D. (p.p.m.)	Oxidation (%)	B.O.D. (p.p.m.)	Oxidation (%)
1	—	—	—	18,100	1.7
2	0.15	4,900	0.46	—	—
4	—	—	—	422,000	39.6
5	1.78	58,500	5.5	—	—
6	—	—	—	582,000	54.5
7	6.29	207,700	19.5	—	—
9	—	—	—	677,000	63.6
10	8.46	279,000	26.2	—	—
15	15.55	512,000	48.1	—	—

* 30 p.p.m. basis.

TABLE X.—Arabinose and Calcium Lignosulfonate, Ratio 1 to 2*

Incubation Period (days)	B.O.D. (p.p.m.)			Arabinose Oxidation (%)
	Arabinose and Lignin	Lignin	Difference	
2	1.24	1.00	0.24	0.8
5	4.45	3.70	0.75	2.3
7	8.12	4.10	4.02	12.4
10	11.50	6.08	5.42	16.8
15	22.30	7.90	14.40	44.6

* 30 p.p.m. to 60 p.p.m.

Xylose

Solutions containing pure xylose were readily oxidized by the microorganisms in the Androscoggin River water, but such activity appears to be severely checked by the presence of calcium lignosulfonate. When this lignin was added to the xylose solution in an amount twice the weight of the xylose present, the rate of utilization of oxygen by the microorganisms was decreased to about one-third of the original rate (Tables XI and XII).

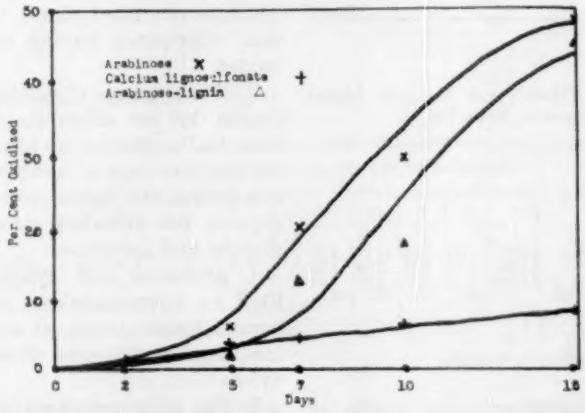

FIGURE 4.—Microbial oxidation of arabinose, calcium lignosulfonate and arabinose-lignin solutions.

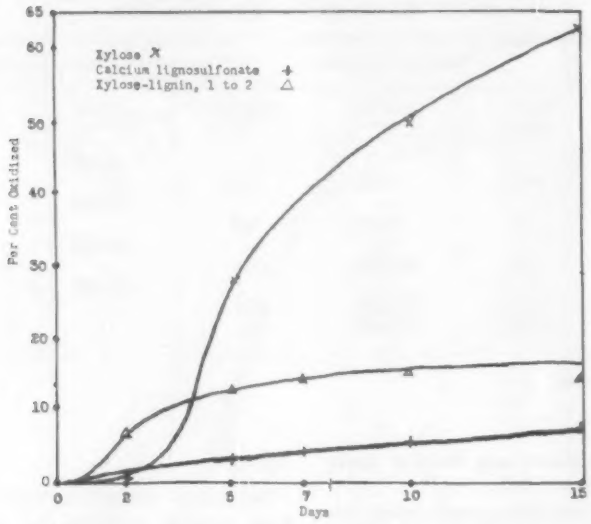

FIGURE 5.—Microbial oxidation of xylose, calcium lignosulfonate and xylose-lignin solutions.

TABLE XI.—Xylose*

Incubation Period (days)	B.O.D. (p.p.m.)	Oxidation (%)
2	0.21	0.64
5	8.97	27.8
7	13.20	40.9
10	16.00	49.6
15	20.30	62.9

* 30 p.p.m.

TABLE XII.—Xylose* and Calcium Lignosulfonate†, Ratio 1 to 2

Determination	Incubation Period (days)				
	2	5	7	10	15
B.O.D. (p.p.m.):					
Xylose and lignin†	3.20	7.85	8.60	11.15	12.31
Lignin† only	1.00	3.70	4.10	6.08	7.90
Difference	2.20	4.15	4.50	5.07	4.41
Oxidation, xylose (%)	6.8	12.9	13.9	15.7	13.6

* Xylose, 30 p.p.m.
† Calcium lignosulfonate, 60 p.p.m.

The data obtained for xylose is plotted in Figure 5 and a statistical summary of the values obtained for all sugars is given in Table XIII.

Conclusions

1. The 15-day B.O.D. of a sample of "pure" calcium lignosulfonate was found to be very small. The Tyrosine test provided confirmation of this observation.

2. No evidence was found to indicate that calcium lignosulfonate, in the presence of carbohydrate, is converted into compounds having high B.O.D. values.

3. The presence of calcium lignosulfonate did not affect the rate of the microbial oxidation of hexoses during the first five days of incubation. After this period, the lignosulfonate tends to depress the oxidation processes with glucose and galactose.

4. Arabinose and xylose were utilized by microorganisms and calcium lignosulfonate produced a marked retardation in the rate of oxidation of xylose.

5. The microorganisms were slow in adapting themselves to pure carbohydrate, either alone or mixed with calcium lignosulfonate, in a Lee and

TABLE XIII.—Summary of Microbial Oxidation Data

Item	Incubation Period (days)					
	2	4	5	7	10	15
(a) GLUCOSE						
Oxidation (%):						
Glucose	0.69	12.6	42.9	48.3	61.2	75.8
Glucose and lignin, ratio 1 to 6	10.5	—	22.5	48.7	58.3	63.6
Glucose and lignin, ratio 1 to 2	0.62	8.4	34.3	48.8	65.1	75.2
Glucose and lignin, ratio 1 to 1	1.18	—	31.0	38.4	45.9	57.1
Difference, oxid. %*:						
Ratio 1 to 6	9.81	—	−20.4	0.4	−2.9	−12.2
Ratio 1 to 2	−0.07	−4.2	−8.6	0.5	3.9	−0.6
Ratio 1 to 1	0.49	—	−11.9	−9.9	−15.3	−18.7
(b) MANNOSE						
Oxidation (%):						
Mannose	2.7	—	35.9	43.4	46.2	51.8
Mannose and lignin, ratio 1 to 6	4.1	—	30.1	51.5	53.3	59.8
Mannose and lignin, ratio 1 to 3	3.1	—	24.9	39.0	46.7	49.3
Mannose and lignin, ratio 1 to 2	1.3	—	42.1	48.7	54.6	54.6
Difference, oxid. %*:						
Ratio 1 to 6	1.4	—	− 5.8	8.1	7.1	8.0
Ratio 1 to 3	0.4	—	−11.0	−4.4	0.5	−2.5
Ratio 1 to 2	−1.4	—	6.2	5.3	8.4	2.8
(c) GALACTOSE						
Oxidation (%):						
Galactose	2.6	—	28.7	53.3	82.2	82.7
Galactose and lignin, ratio 1 to 3	8.8	—	33.4	63.0	67.6	70.9
Difference, oxid. %*	6.2	—	4.7	9.7	−14.6	−11.8
(d) ARABINOSE						
Oxidation (%):						
Arabinose	0.46	—	5.5	19.5	26.2	48.1
Arabinose and lignin, ratio 1 to 2	0.80	—	2.3	12.4	16.8	44.6
Difference, oxid. %*	0.34	—	−3.2	−7.1	−9.4	−3.5
(e) XYLOSE						
Oxidation (%):						
Xylose	0.64	—	27.8	40.9	49.6	62.9
Xylose and lignin, ratio 1 to 2	6.8	—	12.9	13.9	15.7	13.6
Difference, oxid. %*	6.16	—	−14.9	−27.0	−33.9	−49.3

* The difference in per cent oxidation between the pure compound and mixtures of the compound and calcium lignosulfonate.

Nichols dilution water. The addition of organic nitrogen and peptone produced a marked acceleration of acclimatization.

6. Inoculations were made by using Androscoggin River water. This river has received spent sulfite liquor continuously for more than 50 years.

Acknowledgments

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References

1. Anon., "Green Bay Report." Wisconsin State Committee on Water Pollution, Madison, Wis. (1938–39).
2. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).

MEETINGS OF INTEREST

1956

Dec. 9–12 **American Institute of Chemical Engineers,** Annual Meeting, Hotel Statler, Boston, Mass. F. J. Van Antwerpen, Executive Secretary, 25 West 45th St., New York 36, N. Y.

1957

Feb. 18–22 **American Society of Civil Engineers,** Jackson, Miss. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.

Mar. 4–8 **Bavarian Biological Institute,** Munich, Germany. Introductory course on biology of sewage and stream sanitation. Registration closes Feb. 25. Fee $10 (50 DM). Dr. H. Liebmann, Bayerische Biologische Versuchsanstalt, Veterinärstrasse 13, Munich 22, Germany.

Mar. 5–9 **American Concrete Pipe Association,** 49th Annual Convention, Shoreham Hotel, Washington, D. C. Howard F. Peckworth, Managing Director, 228 North LaSalle St., Chicago 1, Ill.

Mar. 11–14 **Second Nuclear Engineering and Science Conference,** Philadelphia, Pa.

Apr. 1–12 **Residential Course on Trade Wastes,** University of Durham, King's College, Newcastle upon Tyne, England. Two-week course on the treatment of trade wastes and the prevention of river pollution. Fee 18 guineas ($52); lodging £15 ($42). Peter C. G. Isaac, Senior Lecturer, Public Health Engineering, Department of Civil Engineering, University of Durham, King's College, Newcastle upon Tyne, England.

Apr. 4–5 **Eighth Annual Pacific Northwest Industrial Waste Conference,** State College of Washington, Pullman, Wash. William H. Knight, Technical Extension Services, State College of Washington, Pullman, Wash.

Apr. 15–19 **Rocky Mountain Water and Sewage Operations School,** University of Colorado, Boulder, Colo. Associate Professor Walter A. Weers, Department of Civil Engineering, University of Colorado, Boulder, Colo.

Stream Pollution

THE HEALTH DEPARTMENT'S ROLE IN NEW YORK HARBOR POLLUTION CONTROL *

By Harold Romer

Director, Bureau of Sanitary Engineering, New York City Department of Health, New York, N. Y.

The penalty society pays for pollution may be judged according to various standards, but by any standard, it is high.

All are familiar with the direct financial penalties of pollution which include depression of real estate values, the limitation of commercial resources, such as shellfish beds, and the depreciation in the value of polluted recreational facilities.

Indirect financial penalties include the additional cost of seeking sport and recreation at distant unpolluted waters, the enforced movement of industry to uneconomical locations and loss of commodities and services that are not produced because of pollution.

The aesthetic penalty is not stated in terms of money, but it is appreciable and becomes greater as civilized tastes and customs advance. The moral penalty is reflected in the manner in which water pollution flouts the principal of mutual responsibility in a close-knit society. The social penalty can be estimated on the basis that water resources are essential to a strong and healthy society.

At the turn of the century Theodore Roosevelt philosophized that "every stream should be used to its utmost." The New York City Department of Health and other responsible agencies concur with this basic philosophy. However, it is also very probable that Roosevelt meant that the use of the waterways should be restricted to planned purposes lest the waters become so fouled that they are destroyed for their intended use.

The City Health Department

The primary justification for expenditure of public funds for sewage treatment is the protection of public health and public welfare. While other agencies of New York City are charged with the construction of sewage collection and disposal works, in the final analysis the Department of Health is responsible for the effectiveness of the over-all program with respect to the safe use of the water resources.

A nationwide survey of local health departments made by the American Public Health Association in 1951 (1), revealed that, of 19 basic environmental sanitation functions, sewage ranked third in order of time devoted. This clearly denotes the importance health departments throughout the United States ascribe to sewage problems.

Sanitary engineers in municipal health departments have, time and again, proven their worth in pollution control problems. The purpose of this discussion is to analyze some of the ways in which departments of health can and have contributed to the conception and execution of pollution control programs. To accomplish this

* Presented at the Metropolitan Section Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; March 14, 1956.

mission the public health engineer must be conversant in the design, construction and operation of sewage treatment works, and he must be expert in making pollution studies and analyzing the results of his labors. As should all engineers, the public health engineer must consider the economics of the situation. Above all, the public health engineer must consider the effect upon the public health and public welfare.

As a control agency, one of the most important roles of a department of health is to coordinate the efforts of the various departments and agencies concerned with the planning of pollution control projects. For example, when plans are made for a combined sewerage system, the necessary overflow relief sewers generally are placed at the most convenient points for the discharge of untreated combined sewage into the river or tidal waters during periods of rainfall. On the other hand, frequently, without knowledge of the significance of these overflow points, the city may plan and build beaches at these very points of discharge. Such situations can be obviated through the aggressive coordination by the department of health of the needs and plans of the departments involved, keeping uppermost in mind the need to attain or maintain good public health. It can readily be seen that if this coordination is lacking, public beaches could be constructed at great expense, and yet create a potentially serious health hazard.

The health department in some cases may declare that abandonment of a combined sewer system in a city is not economically feasible, and recommend that existing or planned beaches be relocated, or perhaps that swimming pools be constructed in lieu of developing beaches. Such was the case in the cities of Boston and Cambridge, Mass., where the beaches along the Charles River were abandoned in favor of swimming pools, at far less expense and greater safeguard to the health of the citizens (2).

The department of health must act as coordinator in public health matters so that where practical greater standardization can be attained. For example, one agency may state that the coliform density of certain receiving waters has been reduced to an M.P.N. of 1,000 per 100 ml. as a result of the installation of a wastes treatment plant. The health department may find the M.P.N. is 5,000. This presents an excellent opportunity for the health department to coordinate the activities of the groups taking samples and performing analyses. A committee should be organized to study the problem and then, by agreement, stipulate sampling locations, phases of the tide when sampling is to be done, the minimum number of samples to be taken, laboratory procedures, etc. Particularly important is the study of sampling results to determine whether they are statistically significant.

Sampling frequently is done over a period of many years according to a set pattern. However, upon close examination of the results, the data may demonstrate little statistical significance. The chance for error in sampling and analysis is very large and unless sound standard procedures are practiced, each agency may be talking a different language which is unintelligible to the others.

Pollution control is a highly technical and complex problem. The nature of the work is such that a high degree of team work by specialists is required to first determine what the problem is, and secondly, to prescribe corrective measures. A pollution control program requires the coordination of the efforts of engineers, chemists, biochemists, sanitarians, hydrologists, oceanographers, biologists, statisticians, mathematicians, and others.

The New York City Department of Health considers the following a reasonable approach to the solution of pollution problems:

1. Determine existing pollution conditions.

2. Determine most suitable water uses.

3. Establish standards of water quality.

4. Determine sources, quantities and composition of pollutants.

5. On the basis of scientifically collected, and intelligently analyzed data, calculate the maximum quantity of pollutants at final points of disposal, which may be discharged without destroying the waters for the uses intended.

6. Predetermine the effect which a poorer grade water will have on an adjacent body of water of higher classification.

Case History

Based on the 1910 studies of the Metropolitan Sewerage Commission (3), as well as its own observations, the Department of Health has been aware of the extent of pollution in New York Harbor. In 1915, Section No. 340a of the Sanitary Code prohibited the granting of a permit to conduct a bathing establishment within 500 ft. of a sewer outlet and along the Hudson River, East River, Harlem River, Upper New York Bay, Kill Van Kull, Arthur Kill, the westerly portion of Raritan Bay, Rockaway Inlet and Jamaica Bay. With the adoption of these rules, the Board of Health, in effect, declared more than 540 of New York City's 576 miles of waterfront as being unfit for bathing because of the proximity of sewage discharges.

In 1936, the Interstate Sanitation Commission was created by agreement between the states of New York, New Jersey, and Connecticut, for the purpose of abating pollution in New York Harbor and other tri-state waters. The Commission classified New York Tidal Waters as follows*:

Class A—Areas expected to be used primarily for recreational purposes (including bathing), shellfish culture or the development of fish life.

Class B—Areas not expected to be used for Class A purposes.

Aware of the consistently increasing pollution and the delay in construction of sewage treatment plants as a result of World War II, the New York City Board of Health adopted in 1948 the standards (Appendix II) for classifying bathing beach waters as either approved or not recommended for bathing.

In 1950 the New York State Water Pollution Control Board promulgated classifications and standards for tidal salt waters. Waters used for fishing, bathing or shellfishing must have a minimum dissolved oxygen requirement of 5 p.p.m. For other waters, a minimum of 3 p.p.m. is required. For shellfish growing areas, the median M.P.N. of the waters may not be in excess of 70 per 100 ml. No bacterial standards were established for bathing waters.

The Problem

The city of New York is confronted with a difficult pollution control problem because of the existence of combined sewers in many parts of the city.

Intercepting sewers, serving combined systems, are designed to carry twice the average dry weather flow. The interceptors are equipped with diversion devices which during periods of rainfall discharge combined sewage in excess of twice the dry weather flow. It is estimated that a light rainfall equal to 0.02 in. per hour will result in the discharge of approximately 30 per cent raw sewage.

The receiving waters remain polluted for a period of one to three days after each rainfall. Review of a 70-year rainfall record reveals that there are approximately one to two rainstorms in excess of .02 in. per hour each week during the summer. With-

* Refer to Appendix I for specific requirements.

FIGURE 1.—Jamaica Bay, New York.

out going into greater detail at this time, it becomes apparent that overflow sewers located relatively close to bathing waters will produce serious bacterial and sanitary hazards. At present, several departments are studying this problem with a view toward sponsoring separate sewers for new installations and eliminating the principal defects in existing combined systems which have been shown to contribute to the pollution of critical waters.

Jamaica Bay

A problem which has received considerable attention during the past three years, vividly points up the need for continuous, close liaison and cooperation among the several responsible agencies. The city has expressed interest in developing Jamaica Bay (Figure 1) into one of the largest bathing, boating, shellfish raising and wildlife areas in the East. Complications, however, have mitigated against the consummation of these plans.

Jamaica Bay is virtually landlocked except for the narrow southerly channel at Rockaway Inlet which allows interchange with tidal waters from the Atlantic Ocean. The average depth at mean low tide, except for channels, is 2 to 4 ft. The bay is approximately five miles long by four and one-half miles wide. These waters appear ideal for the purposes indicated.

Jamaica Bay formerly received raw sewage from approximately 1,000,000 persons. By 1952, the sewage treatment plants needed to handle this load had been constructed and were in operation.

The location of the planned bathing beach is along the north shore of Jamaica Bay at Canarsie. This location apparently was selected because of its position relative to transportation and the existence of a natural beach. A serious problem exists, however, with reference to the use of the waters of Jamaica Bay for bathing and shellfishing. Fresh Creek, a tidal basin, is located immediately east of Canarsie Beach Park. Paerdegat Basin, also tidal, is 1,700 yd. west of Canarsie Beach. During periods of storm flow,

a considerable quantity of combined sewage is discharged into Fresh Creek Basin through a large outfall structure. At Paerdegat Basin a sewage lift station pumps sewage to the Coney Island sewage treatment plant. When this plant cannot handle the combined flow the excess sewage is pumped into Paerdegat Basin. A high service sewer at this same location discharges combined sewage through tide gates into Paerdegat Basin during periods of rainfall.

A study was made of the northern half of Jamaica Bay during the summer of 1954. Samples were collected prior to a rainfall following a dry spell of several weeks. The coliform densities were the lowest on record for this area, indicating good treatment plant performance. The rains came and samples were collected again. The coliform densities at Canarsie Beach as well as at the other sampling points in the northern half of the bay increased terrifically. By the third day after the rain, however, the densities had decreased appreciably. Although not to the pre-rain level they were within the allowable limits for approved bathing waters.

The safety of Jamaica Bay waters for bathing and the advisability of establishing a bathing beach pose questions of public health and economics that must be resolved. Economics are particularly important since large sums of money are necessary for the construction of beach facilities, and it might be necessary to close the beach for two or three days after each summer rainfall, the occurrence of which averages once or twice each week. Extending the sewers to the ocean or providing some adequate treatment for storm flow has been discussed. Because of the extreme costs these solutions have been temporarily discarded.

It would seem that the taking of shellfish from Jamaica Bay would not be safe at any time.

In view of the desirable features of Jamaica Bay for purposes of recreation, the construction of bathing beaches on Broad Channel is now under consideration. Preliminary studies indicate that the waters in the vicinity of Broad Channel show considerably lower coliform densities than most of the waters in Jamaica Bay. However, a more comprehensive sampling program is contemplated in order to obtain a more complete bacterial picture.

The New York City Department of Health, the Department of Public Works, the State Department of Conservation, the State Department of Health and the Interstate Sanitation Commission, as part of a cooperative effort, are at present engaged in studying Jamaica Bay preparatory to recommending a classification scheme for these waters. Whereas Jamaica Bay was classified in 1936 by the Interstate Sanitation Commission, with the consent of the city of New York, as Class A recreational waters, the question arises as to whether it is reasonable to retain the recreational classification.

Methods, Mathematics and Statistics

The Department of Health has a vital interest in the methods, mathematics and statistics of sampling. The sample provides the basic knowledge of receiving waters and to be significant it must be taken in a proper manner, at the appropriate time, and the results analyzed from a valid approach.

Comment is often made about reduced pollution resulting from the completion of pollution control projects. For example, the statement may be made that there has been a reduction of 80 per cent in coliform densities. The correctness of this statement will depend on the degree of accuracy with which the pretreatment and posttreatment conditions of the receiving waters have been determined. The accuracy of the findings will depend, among other factors, on the number of portions used per dilution in the laboratory, the stage of the tidal cycle and

TABLE I.—Logarithmic Average of M.P.N. Values* of Beach Water Samples

Date (Jul. 1951)	Samples (No.)	Tidal Cycle		
		Incoming	Ebb	Full
(a) Point No. 49—N.Y.C. Class B				
18	41	14,300	3,990	7,920
19	36	14,000	4,430	7,880
20	44	6,060	2,660	4,090
21	42	9,550	2,660	5,360
22	43	22,100	6,130	12,200
23	43	21,600	5,080	10,700
24	43	5,570	6,930	6,290
Avg.	—	11,400	4,710	7,290
(b) Point No. 58—N.Y.C. Class A-1				
18	37	4,800	552	2,120
19	35	5,200	866	2,290
20	40	1,750	1,070	1,370
21	42	2,050	1,410	1,730
22	43	4,480	1,640	2,810
23	43	4,570	596	1,750
24	43	1,350	1,260	1,300
Avg.	—	3,100	1,010	1,840

* Log. M.P.N. value per 100 ml.

tidal range when the samples were taken, the number of samples collected, and the statistical approach utilized when analyzing the results of the sampling. In 1952, the author (4) demonstrated the large variations which occurred as a result of each of these items. Unless each factor is carefully evaluated, a compound error of large magnitude will result.

Effect of Tidal Cycle

In the New York area, a tidal cycle consists of approximately six hours of incoming tide followed by six hours of outgoing tide. Samples taken in a popular bathing area (Table I) throughout complete tidal cycles for seven consecutive days showed marked, recurrent variations in coliform densities depending on stage of tide. On the basis of the over-all log. average for that seven day period, the coliform densities during the incoming tides were more than 2.75 times that produced during outgoing tides. Individual days yielded coliform averages up to 8.7 times as great during incoming as compared with outgoing tide. The averaging of incoming and outgoing coliform densities would not present a significant nor valid public health picture.

Despite the lack of epidemiological information, the premise must be accepted that sewage-polluted bathing waters are a potential hazard. In the study of epidemiology, relatively low concentrations of organisms normally have little public health significance, whereas high coliform densities attract the attention of the epidemiologist. This becomes particularly true when the high densities are recurrent over significant periods of time (Figure 2). The low coliform densities have but little interest since, when compared with the high densities, their likelihood of causing disease is remote. Therefore, concern must be directed toward the recurrent, long-period, high coliform densities. To average the high coliform densities with the low densities, thereby producing a low artificial mean, would in effect state that it is safe to bathe in waters of high coliform density for a period of six hours because several hours later the water will have fewer coliform organisms.

Comparative Sampling Methods

Samples taken for comparative purposes must be taken under similar conditions to have any significance. Not only must the samples be taken within close tidal ranges and the same cycle of the tide, but the following factors also must be considered:

1. The effect of nearby combined sewer overflow points, the discharge of raw sewage if it was not raining, and if it was raining, the intensity and duration of the rainfall.

2. The effect of run-off from rivers.

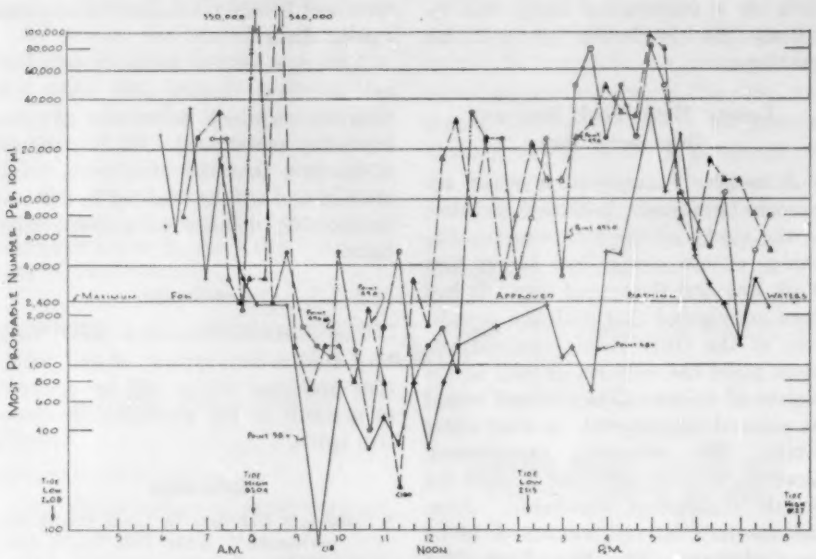

FIGURE 2.—Hourly variation in coliform densities in the Coney Island area, July 18, 1951.

3. The effect of chlorinated sewage plant effluent, and the periods of chlorination.

4. The time of year of sampling, and such factors as temperature and ultraviolet radiation on the bacteria death rate.

Unless these factors are accounted for, samples taken from the same point at different times cannot be compared intelligently.

Liaison and Cooperation

During the past several years, a vigorous and apparently successful effort has been made to strengthen interagency ties. There has been a resurgence of interest and a genuine desire to work together to attain the common goal of pollution control. Several committees have been organized to effectuate this desire. The Mayor's Marginal Pollution Committee was appointed to resolve the pollution problems which have persisted.

An unofficial, interagency laboratory committee has been organized and is actively participating in research work pertaining particularly to the standardization of sampling and laboratory procedures. Results produced to date indicate that the time and temperature of storage of the samples affect coliform densities. Participating in this work are laboratory and engineering staffs of the several interested city departments, the Interstate Sanitation Commission, the State Department of Conservation, as well as several metropolitan county departments of health.

An interagency task force on the abatement of pollution in the metropolitan waters also was organized recently. This group consists of representatives from municipal, state, interstate and federal agencies. The prime purpose is to pool available information on specific problems. Experience has been that in the absence of such pooling of information work already performed by another agency is sometimes duplicated. It is anticipated that as a result of the activity of this group, pooled information, as well as the procurement of additional field

data on a cooperative basis, will facilitate the resolution of pollution problems.

Lower New York Bay and Gravesend Bay

A notable example of a sound approach to a basic pollution problem is the study of the dry weather discharge of raw sewage into Lower New York Bay and Gravesend Bay. It had been anticipated that with the completion of the Owls Head sewage treatment plant the coliform density of the waters of western Coney Island would be reduced to acceptable bathing water levels. The reduction experienced, however, was not sufficient to meet the health department standards. Also, the sanitary survey continued to be unsatisfactory. The New York City Department of Health, with the cooperation and assistance of the office of the Brooklyn Borough President and the Department of Public Works, initiated studies of dry weather, sanitary sewage overflows into Lower New York Bay and Gravesend Bay. The effect of sewage discharges from the New Jersey shores also must be determined before reasonable conclusions can be drawn.

Although certain tentative solutions are in view, considerable additional data are required before the problem is clearly understood. Of importance is the fact that the problem is being studied and will be resolved in a sound engineering manner on a cooperative basis.

Conclusion

The Jamaica Bay and New York Bay studies are typical of the pollution problems which will be resolved as a result of the prevailing cooperative spirit.

References

1. "Sanitary Practices in Local Health Departments." Amer. Pub. Health Assn. (1952).
2. Romer, H., and Eliassen, R., "The Role of Municipal Health Department Engineers in Public Works." *Jour. Amer. Pub. Health Assn.*, **45**, 6 (June, 1955).
3. "Report of the Metropolitan Sewerage Commission." New York, N. Y. (1910).
4. Romer, H., "Critique: New York City Standards for Natural Bathing Waters and Beach and Harbor Water Pollution Control." (1952).

APPENDIX I.—INTERSTATE SANITATION COMMISSION CLASSIFICATION OF METROPOLITAN NEW YORK TIDAL WATERS

Class A Requirements

All sewage discharged or permitted to flow into Class A waters of the district shall first have been so treated:

1. To remove all floating solids and at least 60 per cent of the suspended solids.

2. To effect a reduction of organisms of the B. Coli group (intestinal bacilli) so that the probable number of such organisms shall not exceed one per cubic centimeter in more than 50 per cent of the samples of sewage effluent tested by the partially confirmed test; provided, however, that in the case of discharge into waters used primarily for bathing, this bacterial standard need not be required except during the bathing season.

3. To effect a reduction in the oxygen demand of the sewage effluent sufficient to maintain an average dissolved oxygen content in the tidal waters of the district and in the general vicinity of the point of discharge of the sewage into those waters, at a depth of about 5 ft. below the surface, of not less than 50 per cent saturation during any week of the year.

Class B Requirements

All sewage discharged or permitted to flow into Class B waters of the district shall first have been so treated:

1. To remove all floating solids and at least 10 per cent of the suspended solids, or such additional percentage as may by reason of local conditions be necessary to avoid the formation of sludge deposits in the Class "B" waters of the district.

2. To effect a reduction in the oxygen demand of the sewage effluent sufficient to maintain an average dissolved oxygen content in the tidal waters of the district and in the general vicinity of the point of discharge of the sewage into those waters, at a depth of about 5 ft. below the surface, of not less than 30 per cent saturation during any week of the year.

APPENDIX II.—NEW YORK CITY BOARD OF HEALTH BATHING WATER CLASSIFICATION

Approved Beach Waters

Class A

Group 1—Safe waters.

(a) Epidemiological experience satisfactory; and
(b) Sanitary survey satisfactory; and
(c) Coliform average not in excess of 1,000 per 100 ml.

Group 2—Approved, but subject to reclassification in light of continuing observation.

(a) Epidemiological experience satisfactory;
(b) Sanitary survey satisfactory but beach waters exposed to increasing pollution; or
(c) Coliform average above 1,000 but not in excess of 2,400 per 100 ml.

Polluted Beach Waters Not Recommended for Bathing

Class B

(a) Epidemiological experience satisfactory; but
(b) Sanitary survey discloses sewage material on beach or in water immediately adjacent to beach; and
(c) Coliform average above 2,400 per 100 ml., with 50 per cent of the samples averaging more than 2,400 per 100 ml.

Class C

(a) Epidemiological experience discloses evidence of infection incident to beach bathing.

PROGRAM CHAIRMAN FOR 1957 MEETING NAMED

The Federation Board of Control has appointed George E. (Doc.) Symons as Chairman of the Federation Program and Publications Committee for 1956–57. He succeeds Rolf Eliassen who held this position for two years. The new chairman has served the Federation in numerous capacities including that of vice-chairman of this committee.

Dr. Symons recently accepted the position of Executive Vice-President and Editorial Director of Scranton Publishing Co., effective December 1, 1956. In his new position he supervises all fiscal, production and editorial operations of *Water & Sewage Works*, *Industrial Wastes*, *Modern Highways*, and other publications of the Scranton Publishing Co.

Until the acceptance of his new position Dr. Symons served as consultant and technical editor to several manufacturers in the sewage and water works field. His extensive experience equips him well for the important Federation position of Chairman, Program and Publications Committee.

The first meeting of the committee is scheduled for January at which time initial plans for the Boston Meeting, October 7–10, 1957, will be formulated.

POLLUTION SURVEY SAMPLING OF NEW YORK HARBOR *

By Robert Shapiro

Chief of Laboratories, Department of Public Works, Wards Island, New York, N. Y.

During the period of the rapid population growth of the New York metropolitan area, the domestic wastes produced were usually discharged directly into the nearest watercourse for disposal. This was an understandable procedure from an economic point of view and practically a necessity since there was little understanding of the possible health hazards or of suitable treatment methods. However, the receiving waters, despite the huge volume available for dilution, eventually became overburdened with their putrescent load.

At first this condition was most obvious in the more restricted waterway channels and in the immediate vicinity of sewer outfalls. The continued increase of domestic wastes and the additional industrial wastes spewed into the water then made the putrescible condition most evident. The waters turned grey, became sleeked with oil and odoriferous. The fish left for healthier environs, the waters were a health hazard, recreational areas were restricted, and then water-front real estate values decreased precipitously. By the turn of the 20th century the more progressive engineers recognized the problems to be faced and they were successful in making some of the civic authorities conscious of the urgent need for remedial measures.

The first problem dealt with the extent to which New York Harbor and adjacent waters were actually polluted. The second problem was concerned with the tidal and current distribution of the polluting load. With adequate information, a reasonable answer might be sought as to the type and extent of relief required. Surveys and samplings were needed for this information and they are still used for basic material.

The investigation of New York Harbor was started by the New York Bay Pollution Commission during the 1903–06 period. This was followed by the Metropolitan Sewerage Commission study from 1908 to 1914, with a parallel study by Black and Phelps which was reported in 1911. Other surveys have continued without interruption through the agencies of the New York City Board of Estimate, the Department of Sanitation, and more recently the Department of Public Works. The extent of these records is probably unique in the field of sanitary engineering.

There were many fundamental differences of opinion expressed by the eminent authorities who studied the harbor in regard to the significance of each of the various forces involved, the extent of the load applied, and their conclusions as to the amount and type of treatment required to maintain satisfactory conditions. There were even marked differences between these authorities on the hydraulics of the harbor, for they derive different values for the volume of fresh water brought into the area each day and the extent to which the harbor waters can be expected to be reaerated from the atmosphere. It is with considerable timidity therefore that one approaches any discussion of the extent or distribution of pollution in New York Harbor.

* Presented at the Metropolitan Section Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; March 14, 1956.

Harbor Geography

Some description of the geography of the harbor is necessary for an understanding of the rationality of the sampling program. New York Harbor is a basin in which one principal river (Hudson) and a few smaller rivers (Hackensack, Passaic and Raritan) mix their fresh water with the tide. There are two main salt-water tidal inlets to the inner harbor, through the "Narrows" between Staten Island and Brooklyn and through Throggs Neck where Long Island Sound waters pass between the shores of the boroughs of Bronx and Queens. A relatively small amount of water may be exchanged through Arthur Kills and Raritan Bay.

The distance between the two main salt-water entrances creates a complex tidal pattern, because high tide at Throggs Neck is about three hours behind that at the "Narrows." This causes two tidal crests which meet in the upper East River and result in an appreciable hydraulic slope between the two areas. At high tide at Throggs Neck the resultant difference in elevation permits the entrance of Long Island Sound water, restricts the flow of ocean water into the East River, and limits the flow in the Harlem River. At low tides and for the first few hours thereafter, this situation is reversed.

The inner harbor is further complicated by two large rivers (Harlem and East) which are only connecting channels between larger bodies of water. The importance of this is that these connections permit an interchange of pollution from one area of the harbor to another, while the differences in tidal levels at the opposing harbor entrances can result in a prolonged shuttling of the pollution back and forth, thereby permitting the limited dissolved oxygen supply to be depleted.

The classical float studies made by the New York Metropolitan Sewerage Commission plainly indicated that the discharge of sewage at some points along the harbor shore line may result in sewage being carried by the main currents to distant areas even within a single tidal cycle. In such cases the harbor must be considered as a whole in determining general pollutional loads. Contrariwise, other floats discharged in the vicinity of Wards Island floated back and forth with the successive tidal currents, passing the original point repeatedly until taken out of the water. This shows the need for gathering localized data for each area. It is these complex tidal interchanges between some areas and the prolonged detention periods in other areas, the dual and opposing tidal entrances, plus the entrance of a large fresh water river at a third point which make this harbor so difficult to study or understand.

New York Harbor is a tremendous geological structure which has a water surface area equal to about 60 sq. mi. Within this confined area there are about 336 billion gallons of water, equivalent to about two-thirds of the annual domestic sewage discharged in this area. Even at average low summer flows, the Hudson River contributes approximately 10,000 c.f.s. or 6.5 billion gallons of water per day. A large tidal stream of almost 200 billion gallons of water per day flows through the "Narrows," and a volume of 70 billion gallons per day flows through Throggs Neck. In comparison with these flows of brackish water is the fresh-water use in New York city of one billion gallons per day.

Sampling Procedures

Each year the Department of Public Works charters a boat for use in collecting samples. Forty-five trips are normally planned over a 15-week period from early June through late September. For practical laboratory reasons the trips are made on Tuesdays, Wednesdays, and Thursdays when possible. Four collecting routes are followed: (a) around Manhattan

Island, taking samples in the East River, Harlem River and Hudson River; (b) the East River, taking samples in the Harlem, upper East River and part of Long Island Sound; (c) Staten Island, with samples from the Upper Bay, the Arthur Kills, Raritan Bay and the Narrows; and (d) Jamaica Bay, with samples from the Narrows, the Atlantic Ocean, Rockaway Inlet, and Jamaica Bay. Since the Manhattan trip is the most critical, it is planned for 15 samplings while the others are sampled 10 times each.

The samples are collected in the main channels of the waterway at each station, one from a few feet below the surface and one from a depth of 40 ft. On board the boat the temperature, salinity, and dissolved oxygen are determined immediately and the samples are prepared for the B.O.D. test and for bacteriological analysis. The bacteriological samples (packed in ice) and the B.O.D. samples are delivered to the laboratory and the analyses are started by late afternoon of the same day.

An attempt is made to schedule the various tours so that by the end of the season samples have been collected from each station at various stages of the tidal cycle. In most instances, this can be accomplished by making the trips just seven days apart. Except for hurricanes or very rough weather, the trips are made in either rain or sunshine. On one or two occasions during the past two years, the boat could not be taken out into the Atlantic Ocean beyond the Rockaway breakwater, but on most trips all points are sampled. A few more than 1,000 samplings are made each season.

Once each season, in annual rotation, samples are obtained from one of the three main sources of new water to the inner harbor throughout a 12-hr. tidal cycle. Samples are taken each hour, at the top and bottom of the channel, near each shore and at midstream. When assembled, these data present a cross section of the stream, and help to determine the tidal interchange and quantity of new oxygen brought into the harbor. The data also permit comparison of the results for each three-year interval. Samples are not collected in stormy weather as the data would then be distorted.

The schedule of collecting two samples at each station every week is not an ideal arrangement. A greater number of samples at each station would be desirable as would cross-sectional studies of the waterways. Limitations on money and manpower make a compromise necessary. For the study of the main problem it is desirable to get a general picture of the condition of the principal harbor currents which are transporting pollutional material, rather than try to determine localized pollution near the shores or within the bays. It is desirable to obtain data that are least affected by variations in temperature, rainfall, tidal changes, etc., so that comparisons can be made from year to year.

Conclusion

Other governmental bodies are also concerned with studies of the pollution of New York Harbor. These agencies, local, state and interstate, each have a principal objective and each conducts a survey different to some extent from that of the Department of Public Works.

Anyone making a prolonged study of the behavior of New York Harbor might come to regard it as a sensitive and animated creation, with all the complex responses and vagaries of a living organism. The numerous influencing factors, each modified by the others, so affect its condition and its responses as to make it appear an almost sentient creation, ever-changing and full of surprises.

THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

CENTRIFUGAL PUMP–NOISE CONTROL *

BY L. M. EVANS

Standard Pump Division, Worthington Corp., Harrison, N. J.

Centrifugal pump noises at sewage treatment plants and pumping stations have generally been considered to be a necessary occupational nuisance, but the public has never accepted the theory that noise is a necessity. As community sewage treatment programs have developed, the sewage lift station has moved into more and more residential areas. Lift stations as neighbors may be tolerated but do not bring joy to the immediate homeowners. The slightest odor often triggers a succession of nagging complaints, justified or not, and the same applies to operating noises, such as from the pumping units. This is particularly true at night.

No sewerage system that considers itself to be modern or endeavors to keep up with the times should permit unnecessary pump noise either at the lift stations or at the treatment plant, if not for good public relations then at least for employee morale. A noise level greater than 75 decibels is distracting and adversely affects employee morale. At 100 decibels the noise becomes deafening and above 120 decibels there is pain and possible permanent injury to the ear.

Designers frequently limit the maximum speeds and impeller diameters of pumps to 1,800 r.p.m. and 80 per cent maximum diameter, respectively. While these restrictions may have the desired effect of noise reduction or control with specific pump designs, there is no evidence that the penalty in hydraulic efficiency will be justified. (A poorly designed pump or one not selected to operate at its best efficiency point may operate in a condition of shock or turbulence.)

Noise Trouble Sources

The speed and impeller diameter relate to the frequency and intensity of any noise created by impeller vanes passing under the casing tongue or "cut water." For example, a five-vane impeller running at 1,800 r.p.m. has a frequency of 150 vibrations per second.

$$F = \frac{\text{No. vanes} \times \text{r.p.m.}}{60}$$

$$= \frac{5 \times 1{,}800}{60} = 150 \text{ vibrations per second}$$

This frequency is well within the 20 to 20,000 vibrations per second audio range and, if of sufficient intensity, could be objectionable. A comparable 3,600 r.p.m. pump would have a corresponding frequency of only 300 vibrations per second. Since the average human ear is most responsive to frequencies in the range of 5,000 to 10,000 vibrations per second, either of the frequencies (if generated by the pump vanes) are in the low-response range.

The above comparison of the pump vibration frequencies indicates trouble

* By permission, from *Power and Fluids* (Spring, 1956).

from a poorly designed or improperly selected unit. As a source of noise, the impeller vanes can be disregarded for properly designed pumps that are correctly applied.

In the early stages of the development of centrifugal gas compressors (operating at 5,000 r.p.m.), impeller diameters were limited to create more clearance in the casing and between the vane tips and casing tongue, thereby reducing noise. This thinking cannot be applied to a non-compressible fluid like water. It is more important to select a pump that will operate at best efficiency. Due to excessive turbulence, operating a pump at very low or very high flows can add to the noise problem.

Tests reveal that 3,600 r.p.m. pumps are quieter in some cases than the corresponding 1,800 r.p.m. units. This might be expected, because if the pumps develop the same head, the velocity at the vane tip of the impellers will be the same, no matter what the rotation speed. Noise-level comparisons should be conducted on the basis of pumps of equal capabilities and driven by the same size motors. Since the pumps will vary in physical size, a fair comparison is difficult.

Other Causes of Noise

There are many other sources of noise that should be considered. Noise may be caused by any one or a combination of the following conditions:

1. Coupling misalignment (frame mounted or double suction only).
2. Bent shaft in pump or motor.
3. Rotating part rubbing on stationary part.
4. Distorted baseplate due to uneven or improper tightening of foundation bolts.
5. Improper seating of pump baseplate.
6. Pipe strains on pump casing.
7. Defective or loose bearings.
8. Unbalanced rotor in either pump or motor.
9. Excessive axial play on motor rotor.
10. Excessive motor windage noise, poor fan design.
11. Pump operating in "cavitation" range.
12. Pump operating in "hunting" or unstable condition (usually at excessive capacity).
13. Pump "churning" back near shut-off.
14. Water hammer.
15. Piping not properly supported.
16. Valves, fittings, and controls not properly selected or adjusted.
17. Pump generating hydraulic noise as impeller vanes pass under casing tongue (in poorly designed pumps).
18. Pump speed which sets up sympathetic vibrations in piping system, causing an increase in the amplitude of vibration.
19. Motor emitting 60-cycle "hum."
20. Water velocity too high in piping system or sharp bends in the piping, resulting in turbulent flow.

Common-sense precautions will generally permit the use of an inexpensive standard pump of highest hydraulic efficiency. Some of these causes of noise should be considered further.

Coupling Misalignment

Excessive noise with frame mounted or double suction pumps can, in most cases, be traced to coupling misalignment. The alignment should be checked after the pump has been secured on its foundation, the piping has been installed, and the system is operating at its normal temperature. Alignments should be made with a dial indicator shaft to shaft. It should be rechecked after one week, one month, three months, and then at least once every year.

Exposed shafting (with coupled units) is frequently bent by careless handling or lack of protection during construction work. However, a close-coupled pump eliminates misalignment as a source of noise.

Baseplate

To prevent a drum effect from the baseplate, the space beneath the base should be filled with grout. This is done after alignment checks have been satisfactorily completed.

Unbalanced Rotors

Special instruments such as a Vibraton are required for checking and remedying unbalance of the rotor in the field. Damage to couplings or short coupling keys can cause unbalanced pump or motor rotors. Solids in the water may scour or erode parts of the rotating element until an unbalanced condition is produced. Occasionally, however, the unbalance is caused simply by a piece of foreign matter lodged in the impeller.

Axial Play

Excessive axial play in a motor rotor can produce a beating or throbbing noise and contribute to bearing failure. The motor shaft must be free to seek its magnetic center for normal load conditions and, in general, the motor and pump shafts should not be permitted to contact or butt together at the ends.

Hydraulic Noise—Cavitation

Every pump will operate quietest at its best efficiency point, as this is the condition of minimum turbulence. When the pump operates near shut-off or out at the "break" of maximum capacity, it gives off excessive noise. Maximum shaft deflection usually occurs at shut-off head. Consequently, the rotor is subject to the greatest vibration at that same point. Cavitation at maximum capacity produces a noise characterized by an erratic "hissing" or "crackling" and, in time, will cause packing trouble, bearing failure, and destruction of the impeller. Cavitation sets the pump rotor in vibration due to unbalance, and this vibration is often referred to as "cavitation beat."

Pipe Strain

The pump casing must be free from piping strains. Flexible rubber couplings for both suction and discharge are recommended, and armored metal hose is suitable for simply preventing pipe strains. It is very important to avoid stretching the metal hose to make up for short piping connections, because the hose will then act as a solid length of pipe, pulling on the pump. With metal hose connections, any vibrations present in the pumping unit may still be transmitted from the pump out into the piping system. Flexible hose connections, however, do serve to prevent noise resulting from misalignment caused by pipe strain.

Field Tests

Vibration and noise in a pumping unit can travel out into occupied space through the following paths:

1. The piping.
2. The foundation structure.
3. The surrounding air.

When a noise is found to be due to the pumping unit, the problem can usually be solved by blocking the transmission of vibration and noise along each of these three paths.

The following step-by-step procedure will indicate which path is causing the trouble:

Disconnect the suction and discharge piping. Run the pump dry (supply water through a hose to the packing and seal), and compare the noise in the occupied space with the original condition.

If the noise is reduced, then the piping must be the carrier. If the condition is not improved, then the vibration is following another path. Proceed to next step.

Lift the pump and motor unit off the foundation. Insert special rubber pads under each foot so that the weight is carried evenly. A material which can be used is isomode neoprene. A piece 5/16-in. thick should be cut into

pieces in order to have a loading of 50 lb. per square inch to be effective in preventing the transmission of vibration. The deflection of the neoprene pads will be about 1/16 in., or the thickness under load will be about ¼ in. Run the pump again on the pads (without tightening down the foundation bolts).

If the noise is reduced, then transmission has been taking place through the foundation to the building structure. If the noise condition is not improved, then there must be an airborne path.

Each of these paths for vibration transmission is tested successively. Therefore, for installations complicated by supports, accessory piping and metal sheathed electrical conduits, etc., it is necessary to improvise means of running the unit.

When observations indicate that the pump or motor is producing an abnormally high noise level, it is often possible to isolate the noise by making the following checks:

1. Close the discharge valve while the pump is operating in the system. Open the discharge valve wide and gradually close the suction valve to starve the pump and produce cavitation. Observe changes in noise level associated with operating the pump in the poor efficiency zones of shut-off and cavitation.

2. Remove the impeller and run the pump dry, but with water on the packing or seal. A reduction in noise level under these conditions may be attributed to unbalance in the impeller.

3. Remove the packing or seal and again run the pump dry. A reduction in the noise level here indicates that it was due to rubbing surfaces in the gland.

4. Remaining noise on the pump end can be attributed to bearing or coupling misalignment.

5. Disconnect the coupling and run the motor by itself. A reduction in noise level indicates there was noise in the pump bearings or coupling.

6. Remove the coupling from the motor shaft and operate the motor by itself.

7. Remove the motor fan and operate long enough to compare noise level. Usually motor noise is caused by poorly designed fans. The remaining noise can be attributed to bearings or unbalanced rotor in the motor.

Instruments and a laboratory setup with a soundproof room are required in order to make a complete analysis of noise problems in pumping machinery. However, the checks given above are useful for trouble shooting in the field.

Noise Control

Since it is impossible to eliminate all sources of noise in a pumping unit, the most practical approach is to isolate the pump or any other source of noise in the system. Noise in hydraulic systems is mainly transmitted through the metal to metal piping or supports. In relation to steel or cast iron, water attenuates or dampens noise. Since metal piping is the best transmitter of noise and vibration, it is necessary to devote special attention to isolating the pumping unit through the use of non-metallic connections (Table I).

TABLE I.—Comparison of Acoustical Impedances*

Material	Sound Velocity (in./sec.)	Relative Impedance
Steel	206,500	500
Copper	140,400	425
Cast iron	148,800	365
Concrete	198,600	134
Water	56,400	19
Pine	132,000	18
Cork	19,200	1.6
Rubber	2,400	1.0

* Low impedance corresponds to low sound transmission. Acoustical impedance is the product of density times the velocity of sound in the material.

High-pressure, high-temperature rubber hose connections are more effective than most devices for controlling noise transmission from pumps into the system. These rubber hose connections also prevent piping strains on the pump casing. The higher the frequency of noise, the shorter the hose connections permissible (Table II).

TABLE II.—Length of Rubber Connections Recommeded to Attenuate Low Frequencies

Pipe Size (in.)	Over-all Length (in.)
1	18
2	24
3	36
10	48
12	60

However, hose connection lengths are generally based on preventing the transmission of the low frequency vibrations. Also, to be most effective, the flexible hose connections should be mounted vertically.

Piping Supports

Piping not isolated by rubber connections, but connected directly to the pump or other source of vibration, should be resiliently supported by suitable hangers. This prevents transmission of vibration to the building structure. Piping isolated by means of rubber connections and free of any system vibration may be rigidly anchored. Remember that even though the piping may be isolated, noise can be created by sharp bends in the pipe or restricting valves and fittings. The safest practice, nevertheless, is always to isolate piping from the building structure to prevent any vibrational forces from being passed to the structure.

Whenever tie rods are required for resilient supports, resilient or rubber washers and bushings must be used on all connections to eliminate metal-to-metal contact.

Isolation Mounts

Pumps installed in buildings where the vibration must be isolated from the structure should be mounted with rubber or cork under the foundation blocks. Vibration eliminator bases are commercially available for pumps. Rubber piping connections must also be used on the pump to isolate vibration.

Many installations are effectively treated by using neoprene pads under the feet. The nuts are left off the foundation bolts so that the proper deflection of the neoprene will be insured. The loading (50 lb. per square inch) must include all forces as well as weight. Neoprene sleeves should be inserted around the foundation bolts so the vibration will not be transmitted from the baseplate or feet to the bolts tied in with the building structure.

Air-Borne Noise

Since motor windage noise is air-borne, it is generally confined to the machinery room. It may be noticeable to the operators, but it seldom reaches people in other areas unless there is a direct air path from the motor location.

However, air-borne noise can be limited by:

1. Consulting motor manufacturers for instructions or recommendations, giving special attention to fan design.
2. Using absorptive material around motor air intake and discharge ports.
3. Applying acoustical treatment to pump area. Soft material absorbs sound. Hard material reflects and builds up the sound level.
4. Enclosing the pump area with sound barriers to reduce straight line propagation of high frequency sounds.

When air-borne noise from machinery is being considered, background noise must be taken into account. Noise level as measured in decibels is not a reliable criterion for comparisons. The pitch and other factors

must also be considered. Non-cyclic noises are generally more noticeable than corresponding cyclic noises.

Summary

Pump noise is a system problem. It is generally more practical to isolate the noise than attempt to eliminate it.

Hydraulically generated noises represent only a few of the possible sources of noise in a pump system. Compromising pump performance, in an effort to eliminate, or just reduce pump noises, often defeats the purpose and is seldom justified.

EXPERIENCES WITH ODOR CONTROL AT HOUSTON, TEXAS *

By A. C. Bryan

Superintendent, Sewage Treatment Plants, Houston, Texas

This discussion is concerned with three different odor types as experienced in connection with the operations of a large sewage treatment plant. These odors may be grouped into the following general classes:

1. Sulfide odors—septic sewage.
2. Scum odors—decomposing grease.
3. Protein odors—dried sludge.

Sewage works odors are such heterogeneous mixtures of basic odors and vary in composition so widely from one situation to another that it is appropriate to try to describe each odor in several different ways. It is hoped that the reader will be sufficiently able to identify the odor with some personal experience of his own. Perception and identification of odors vary so widely among individuals that communication on the subject becomes difficult. This varying characteristic of olfaction among humans also complicates evaluation of odor control measures.

Sulfide Odors

Sulfide odors are most commonly associated with the odor of rotten eggs, sharp rather than musty. It is generally associated with septic sewage or sludge and almost invariably accompanies the drawing of primary sludge if the sludge has remained in the settling tank several hours. In the case of a long trunk sewer in Houston, the hydrogen sulfide concentration reached a sufficient level to cause a public nuisance over a considerable area near the treatment plant headworks.

Several methods have been investigated in an attempt to abate this type of odor nuisance. In April 1953, sodium nitrate was added to the sewage at various pumping stations along the trunk sewer to provide sufficient oxygen to inhibit the formation of sulfides, hence abate the odor. The experiment was conducted for a sufficient period of time to establish that the method accomplished the intended purpose. Approximately 10 lb. of sodium nitrite were used for each pound of sulfide normally present in the sewage. In this particular system it was estimated that complete and continuous abatement would cost about $40,000 annually or an amount equal to about 25 per cent of the total operating cost of the activated sludge treatment works. Obviously this method has not been accepted as standard operating practice.

Experimental work also was undertaken in 1953 to show that compressed

* Presented at 1956 Texas Water and Sewage Works Short School; College Station, Texas; March 5–9, 1956.

air would effectively prevent sulfide formation in long force mains. A design criteria was not developed because the effectiveness of the method seemed to be a trial-and-error proposition to fit the sewage characteristics, pipe line detention, and pressure conditions. Suffice it to say, 75 c.f.m. per million gallons of sewage per part per million of sulfide completely inhibited the sulfides. This appears to be very practical within the limits of its application. Installation work is now under way on a 7,000-ft long, 12-in. diameter force line which utilizes a 50 c.f.m. compressor.

Chloroben has been tried without success in reducing the cost of odor control. So far the cost exceeds that reported for the use of sodium nitrate.

In February 1956, iron salts were introduced up-sewer to bind up chemically the sulfides. Feeding rates varied up to 12 tons of Ferri-Floc per day with a flow of 26 m.g.d. Odor reduction was negligible and there was only a slight reduction in dissolved sulfides. At $45 per ton the cost of treatment with Ferri-Floc amounted to $21 per million gallons of sewage. This test was made on a 48-hr. run only, but the economics appear to preclude further study.

Sealed coverings over open channels and structures where sulfide odors were emitted result in excessive corrosion of the concrete structures.

An odor counteractant is currently being used at one of the large treatment plants for nuisance abatement. The method depends on aspiration of a fine mist of the counteractant into the atmosphere in the area of origin of the objectionable odor. Its success depends on mixing the proper amount of counteractant with the objectionable atmosphere to obtain the effect of no odor. Overfeeding the aspirators will produce the odor of the counteractant. Underfeeding permits perception of the objectionable odor. Between these two limits is the range of no-odor perception. A reasonable degree of success is being achieved, although for best results complete mixing with the atmosphere is necessary. If there is insufficient mixing or if the observer is too close to the point of application, each odor is individually perceptible.

The cost of this application is currently about $13 per day. Like several other corrective measures this is one where it is difficult to establish definite criteria for installation purposes. A trial-and-error procedure appears to be best for establishing the number of nozzles required and the proper dilution of counteractant and odor.

Scum Odors

Scum odors are usually experienced where grease decomposition is found, i.e. as around rendering plants, grit removal and screening devices, open digesters, lagoons with a scum layer, and aeration tanks where dried froth has built up a scum layer on tank walls and surrounding areas. It is this scum on the aeration tank walls that has received considerable attention at the Houston works.

During the years 1950–53, 20 to 25 defoamants were studied, including 10 different polyglycols (alcohols), kerosene, silicone, National Aluminate products, Swift & Company products, Socony-Vacuum products, American Aniline products, and tall oils. All of these products were explored for the purpose of determining their effectiveness in preventing froth, hence abating the odor of scum by eliminating froth formation. Of all the products tried only tall oil would accomplish complete control of froth both in the treatment plant and on the receiving stream.

Tall oil was placed in continuous plant-scale use at one of the plants for a 12-month period beginning in April, 1953. The 12-month application cost was approximately $23,000 ($65 per day) or about 13 per cent of the total operating cost of this activated sludge plant.

During 1955 a final effluent spray system was installed over the aeration tanks, using about ¾ gal. of water per linear foot of aeration tank length. This spray system cost was approximately $20,000 for the installation and about $8 per day for electric power. The system is only about 50 per cent as effective as tall oil. The next step will be to investigate the possibility of mixing defoamants in the spray water for additional benefit.

Heated Protein Odors

A third type of odor characteristic of a large plant installation is a heated protein-type odor associated with stack vapors discharged from the sludge drying process. "Over-roasted peanuts" is one descriptive phrase that has been applied to this odor. Another observer called it a "kitchen stove" odor which may be encountered where heavy meat frying is in operation.

Washing these stack vapors with water has been only moderately effective. Two spray nozzles are presently used at the top of these stacks to aspirate an odor counteractant into the vapor plume. Each nozzle aspirates a separate formula to obtain the combined effect of two counteractants. This application is costing about $30 per day and is only partially effective (probably 75 to 80 per cent). Careful attention should be given to nozzle installation in order to avoid frequent maintenance trips to the top of the stack.

Incineration or after-burning has been reported to be effective for eliminating this type of odor. However, facilities for this type of control require substantial design considerations and are best incorporated at the time of incinerator construction.

Conclusion

There appear to be few substantial data on odor control experiences at sewage treatment plants. Odor problems are very real to the operator or superintendent who has to contend with complaints caused by his sewerage system. Many operators would be pleased to have research work undertaken on some of these odor control problems. Perhaps the air pollution researchers can devote a little time to sewage odors.

SEWAGE SAMPLING AND PLANT PERFORMANCE*

By D. P. Backmeyer †

Superintendent, Little Miami Sewage Treatment Plant, Cincinnati, Ohio

Efficient sewage plant operation depends to a great extent on the plant supervisor's knowledge of the volume of flow and the quantity of solids entering and leaving his plant. Gauging of flow is commonly done by flow meters which give reliable records of volume, usually in gallons, of raw sewage flowing into the plant.

In addition to volume of flow, the quantity (in pounds) of sewage solids present in the flow should also be known. The efficient performance of the treatment plant is contingent upon the removal of these solids. To determine the quantity of solids in the raw sewage as it enters the treatment plant, and also in the treated effluent which is discharged from the plant, it is necessary to take samples of the sewage and to make standard laboratory tests. It is of prime importance that each sample be representative of the

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* Newsletter, Sewage Disposal Section, Division of Engineering, Cincinnati, Ohio (July, 1956).

† Presently, Superintendent, Miami Sewage Treatment Plant, Miami, Fla.

material being sampled. Considerable thought and study may be required to devise a sampling technique that is adequate and at the same time is simple and easy to perform.

A method known as the "weighted composite method" is perhaps the most accurate and most commonly used. A weighted composite sample is obtained by taking portions of the sewage at a given time and location and using a quantity in proportion to the quantity of flow as measured by a meter or similar device. As an example, if samples are collected hourly, the composite would contain 24 portions per day and each of the 24 portions would represent a given quantity of flow. If, for a selected period of one hour, a pint of sample was taken for a million gallons of flow through the plant, then for another hour period in which the flow was two million gallons, the operator would place two pints of sample in the composite container. If the total flow for the day was 24 million gallons, the daily composite container should contain 24 pints when received at the plant laboratory.

The plant chemist uses this composite sample for several chemical tests. When he withdraws a portion of sewage from the composite bottle for a particular test, the chemist must also be sure that he is taking a portion of the sample that is representative of the composite sample. His work is done with special analytical apparatus and is precise. No matter how high a degree of precision is obtained in the laboratory, it is the initial collection of the sample in the field that determines primarily the real value of the sampling. Carelessness in taking and handling sewage samples cannot be permitted if a sound and reliable appraisal of plant performance is the ultimate aim of the sampling program.

INTERESTING EXTRACTS FROM OPERATION REPORTS

"If you think you are beaten, you are."—G. W. Longenecker

Attention operators! It will be appreciated if copies of the annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Annual Report of the Division of Sewage Disposal, Cleveland, Ohio, for the Year 1954

The extensive improvements to the Cleveland sewage treatment plants were progressing very satisfactorily. Increased demand for water, together with the rapid development of the suburban areas, is responsible for the present expansion and improvement program.

The total long-term debt by the Division was $9,571,000. Operating revenues totaled $2,261,398, an increase of $174,612 over 1953. Total cost of operation and maintenance of the treatment facilities was $1,990,670.08, an increase of 6 per cent over 1953. The increase can be allocated as follows:

Plant operation and maintenance	$ 6,987.45
Administrative and other costs	31,804.33
Annual depreciation	71,336.34
Non-operating expense	4,305.72
Total	$114,433.84

The increase in depreciation was caused by the completion and placing in operation of new additions to the Southerly plant.

Although the Division has met its obligations, its financial condition is not satisfactory. Although revenue cash receipts were the highest in the Division's history, principally due to speed-up in billing (from semiannually to quarterly), the net income is not sufficient to finance safely an operation of this size.

Net earnings plus annual depreciation have been barely sufficient to pay the maturing bonds. However, sizeable incomes were received from invested bond and revenue funds. When these funds are used to pay for construction work, the total revenue of the Division will be insufficient for proper operation. Suitable rate adjustments upward will be necessary.

Report on the Operation and Maintenance of the Easterly Sewage Treatment Plant, Cleveland, Ohio, for the Year 1954 *

By John J. Wirts, *Superintendent*

The average daily flow to this sewage treatment plant increased from 101.9 m.g.d. in 1953 to 103.9 m.g.d. in 1954. This reflected to some extent the increase in water consumption in the Cleveland area and the continued growth of suburban residential areas. Operating efficiencies were maintained at satisfactory levels, equal to or better than the preceding year.

The Easterly treatment works treats an average of 103.9 m.g.d. and is the largest of the three Cleveland plants. Located along a one-half mile stretch of Lake Erie shoreline, in a first-class residential area, the treatment plant grounds and waterfront have been subjected to increased use as a summer recreational area. A boat harbor, two bathing beaches, one large parking area, and a picnic ground have been developed.

The principal function of the treatment plant, which is to safeguard public health, must be constantly defended when efforts are made to obtain additional plant property for recreational use. Odor and frothing problems, which occur in conjunction with the treatment of sewage, are potent reasons for keeping recreational activities away from process equipment.

The high removals reported for this treatment plant apply only to the tributary raw sewage. Sources of pollution to the lake include storm-water overflows, industrial wastes, surface wash from streets and refuse dumps, and wastes from commercial and pleasure craft. A considerable increase in pollution can be expected as a result of the St. Lawrence Waterway traffic and accompanying expansion of dock facilities.

Full-time employees numbered 56 and shift supervision was reduced to 8 hr. per day, seven days a week. Reasonably satisfactory operation supervision has been achieved by occasional overtime during emergencies. Operating and maintenance costs were maintained at nearly the same level as in the previous year. Power costs, during the months of June, July and August, were the highest on record due to the lack of rain during these three months and the necessity for operating two large blowers to maintain sufficient dissolved oxygen for effective treatment.

Comminutors and Detritors

The comminutors were in service for 16,118 hr. and handled 79.5 per cent of the total raw sewage flow to the plant. The large quantity of grit passing through these units had an

* For last previous extract see This Journal, **27**, 8, 977 (Aug., 1955).

TABLE I.—Summary of Operating Data, Easterly Plant, Cleveland, Ohio, for the Year 1954

Item	Average 1954
Raw sewage flow (m.g.d.)	103.9
Settled sewage flow (m.g.d.)	98.2
Grit removed (cu. ft. per m.g.)	3.3
Screenings (cu. ft. per m.g.)	0.26
Suspended solids (p.p.m.):	
Raw	198
Settled	114
Effluent	11.3
Removed (%)	93.8
B.O.D. (p.p.m.):	
Raw	147
Settled	91
Effluent	10.3
Removed (%)	93.0
Oxygen consumed (p.p.m.):	
Raw	82
Settled	56
Effluent	18
Reduction (%)	78
Dissolved oxygen (p.p.m.):	
Presettled raw sewage	1.9
Aerator influent	1.9
Aerator effluent	2.4
Final effluent	2.5
Ammonia (p.p.m.):	
Raw	15.9
Settled	10.3
Effluent	9.7
Nitrite, effluent (p.p.m.)	0.2
Nitrate, effluent (p.p.m.)	2.8
Sludge pumped to Southerly plant, total (m.g.)	203.93
Moisture (%)	96.5
Activated sludge:	
Total solids (p.p.m.)	5,949
Volatile solids (%)	64.1
Mixed liquor susp. solids (p.p.m.)	1,419
Sludge index (ml./gram)	101
Air (cu. ft./gal. settl. sew.)	0.78
Postchlorination:	
Days applied, total	88
Application rate (p.p.m.)	3.7
Residual (p.p.m.)	1.2
Bacterial count; agar plates at 37½° C. (1,000 per ml.):	
Raw	1,934
Effluent	38.3
Reduction (%)	98
Presumptive *B. coli* (1,000 per ml.):	
Raw	133
Effluent	1.7
Reduction (%)	98.7
Plant costs ($ per m.g.):	
Operation and maintenance	21.16
Administration	14.89
Total	36.05

adverse effect on the bottom and middle sections. Replacement cost of these sections on one of the four comminutors will exceed $11,000.

Routine replacement of cutting elements totaled 1,041 teeth, 33 combs, and 212 shear bars. Most of these replacements were made from reconditioned elements.

Grit removal in the detritors continued satisfactory, whereas the efficiency of the grit chambers decreased. In 1954, grit removal amounted to 27,243 cu. ft. from 20.5 per cent of the total sewage flow. This compares with 23,301 cu. ft. of grit removal in 1953 from 9.4 per cent of the flow. The badly worn drainage pump was replaced.

Collinwood Pumping Station

The pumps average 18 to 30 years in age and range in condition from fair to poor. Parts are not stocked and must be made to order by the manufacturer.

Pump No. 2 had decreased in capacity from 8 m.g.d. to 2 m.g.d. and pump No. 5 was operating at 10 m.g.d. versus a rated capacity of 15 m.g.d. New parts and extensive rebuilding by plant craftsmen improved the capacities of these two pumps so that they can deliver 11 and 15 m.g.d., respectively.

These pumps have operated for 21 months without the benefit of a comminutor. However, the 3-in. bar screen was replaced with a 1.5-in. screen to reduce blockages further.

The first discharge section of the Venturi meter developed a leak 2 in. in diameter. Tests of the section revealed that the cast iron had eroded from an original thickness of 1 in. to a thickness of 3/16 in. The entire discharge section has been encased in 6 in. of

reinforced concrete and a replacement section ordered.

Aeration Tanks and Blowers

There was little change in the operation or the efficiency of the activated sludge tanks. The sludge index averaged 101 and the mixed liquor suspended solids averaged 1,419 p.p.m.

Diffuser plates in tanks Nos. 2, 4, 6 and 9 were replaced. The steel manifolds in these units showed extensive rusting.

Frothing of the aeration tanks continues to be a serious problem. The froth spills over onto the concrete walks between the tanks, and onto the surrounding shrubbery and grass. Particles of grease and sludge are carried with the froth and accumulate as a heavy, foul-smelling scum, ⅛ to 3 in. thick. Many man-hours are required to clean the walks and reduce the odor.

A 50-ft. length of drilled pipe was successfully used to spray plant effluent on the foam in one of the tanks. The cost of installing water sprays on all the tanks and pumping the effluent is a major item under consideration that will require study. If this froth problem follows the pattern of detergent problems in other cities, the existing conditions can be expected to become worse.

Operation data for 1954 are summarized in Table I.

Report on the Operation and Maintenance of the Westerly Sewage Treatment Plant, Cleveland, Ohio, for the Year 1954 *

By John O. Barrett, *Superintendent*

General

The average flow received at the Westerly sewage treatment plant for the 10-year period, 1943–52, was 32.7 m.g.d. The flow for 1954 was 33.6 m.g.d., which was slightly greater than that of the previous year and the fifth largest in plant history. Flows in excess of 72 m.g.d. are diverted to an overflow channel. The recorded overflow averaged 27.2 hr. per month. Population served by this plant is estimated to be 223,500, but the population equivalent is calculated to be 279,000, based on 0.167 lb. of B.O.D. per capita per day.

An engineering report recommending improvements which would increase the over-all efficiency of the plant was approved in December 1954. Construction of modern screening devices, new detritors, grit disposal equipment, and preaeration tanks is expected to cost about $625,000.

Operation was near normal. Pig hair and entrails from slaughter houses continue to be a troublesome problem.

Sedimentation

Hourly samples are collected and composited daily. The percentage reductions of suspended solids and B.O.D. were less than during the previous year, and the suspended solids removal was equal to the 10-year average, 1943–52.

The Imhoff tanks at this plant are used only as primary sedimentation units; digesters handle the sludge. An accelerated program of pumping down the Imhoff tanks and washing the slots was instituted to keep the tank slots open.

A number of gas vent lids were replaced. The 1-in. risers on the raw water sprays of one of the tanks were replaced by rigid polyvinyl chloride plastic pipe in an attempt to solve the corrosion problems.

* For last previous extract see This Journal, **27**, 8, 980 (Aug., 1955).

Chlorination

Pre-chlorination was practiced from June 16 to September 9 to reduce odors and help prevent gas vent foaming. The dosage averaged 5.2 p.p.m.

The location of Edgewater Park bathing, fishing and boating facilities adjacent to the treatment plant requires that post-chlorination be used to keep the bacterial content of the plant effluent as low as possible.

The feed is adjusted hourly during the summer season in an effort to maintain a residual of approximately 1 p.p.m. A dosage rate of 7.8 p.p.m. was required to maintain a residual of 1.61 p.p.m. This was accomplished 73.7 per cent of the time.

The presence of industrial wastes having a high chlorine demand taxed the chlorinating equipment to capacity on several occasions.

Sludge Digestion

Ever-increasing scum accumulations in the six digesters continued to be the principal problem. A rigid recirculation program was followed; each digester was recirculated for a 4-hr. period on the day charged. Sludge was pumped to the digesters daily except on Sunday.

Starting in February, one digester was pumped down each month and the scum removed. Two of the Imhoff tanks are used as scum receivers. By September, scum layers in the digesters had developed to such an extent (9 ft.) that three digesters were emptied for the second time. The heavy scum accumulations caused considerable damage to the steel pipe supports and guy wires in the digesters. One broken cast iron gas line was replaced by galvanized wrought iron pipe.

The gas recirculation study, initiated in 1953, was continued throughout the year. Some breaking up of scum formations occurred but gas recirculation did not prove to be the solution to this problem. The borrowed blower equipment proved to be of insufficient capacity. The lack of openings in the digester lids, to permit better distribution of the recirculated gas, is believed to be a major factor in the poor results obtained.

The quantity of fresh solids added to the digesters was considerably less than that of the previous year. The monthly average of dry solids was 930,000 lb. compared with a 10-year average of 1,010,000 lb. Supernatant totaled 13 million gallons and was returned to the plant influent.

Three new hot water boilers were purchased to replace corroded boilers in the digester heating system.

Sludge Filtration

The four 165-sq. ft. vacuum filters were again operated at near capacity during the greater portion of the year. Large quantities of scum made high production rates easy of attainment. However, poor burning properties and limited cake demand necessitated occasional curtailment in production.

Cake production was at the rate of 3.53 lb. per square foot of filter area per hour. The total production of sludge was the second highest on record and missed the amount produced in 1953 by 169 tons.

Filter cloth showed an increase in hours of service from 117 hr. to 176 hr. A considerable amount of maintenance was necessary. The piping in one filter was cleaned with an acid bath and that in another unit was replaced with rigid polyvinyl chloride pipe.

Incineration

Incineration followed an unusual pattern due to varying conditions. When the scum content in the sludge was extremely high the production rate of the cake was as high as 75 tons per day. At these times the cake was like a carpet and did not break up on the conveyor belt. If all the cake was directed to the stock pile, the chute be-

TABLE II.—Summary of Operating Data, Westerly Plant, Cleveland, Ohio, for the Year 1954

Item	Average 1954
Raw sewage flow (m.g.d.)	33.6
Grit removed (cu. ft. per m.g.)	2.8
Screenings (cu. ft. per m.g.)	0.32
Suspended solids (p.p.m.):	
Raw	245
Imhoff tank effluent	164
Removed (%)	32.9
B.O.D. (p.p.m.):	
Raw	166
Imhoff tank effluent	131
Removed (%)	20.9
Oxygen consumed (p.p.m.):	
Raw	139
Imhoff tank effluent	121
Reduction (%)	12.9
Total bacteria (1,000 per ml.):	
Raw	2,591
Imhoff tank effluent	974
Reduction (%)	62.4
Presumptive *B. coli* (1,000 per ml.):	
Raw	489
Imhoff tank effluent	116
Reduction (%)	76.2
Pre-chlorination:	
Days operated	84.1
Average dose (p.p.m.)	5.2
Post-chlorination:	
Days operated	86.4
Average dose (p.p.m.)	7.8
Average residual (p.p.m.)	1.6
Raw sludge to digesters:	
Number of additions per month	72
Temperature (°F.)	64
Volatile solids (%)	66.8
Total solids (%)	6.4
pH	6.3
Alkalinity as $CaCO_3$ (p.p.m.)	610
Digester supernatant:	
Total solids (%)	0.63
Volatile solids (%)	51
pH	7.9
Alkalinity, as $CaCO_3$ (p.p.m.)	1,990
Gas production:	
Daily production (cu. ft.)	148,200
Cu. ft. per lb. volatile solids	7.2
CO_2 (%)	28.1
Gas utilization (%):	
Digester heaters	27.2
Building heaters	18.9
Incinerators	32.5
Wasted	21.4
Digested sludge vacuum filtered:	
Total solids (lb. per month)	584,400
Total solids (%)	7.14
Volatile solids (%)	53.8
pH	7.8
Alkalinity, as $CaCO_3$ (p.p.m.)	1,840
Chemical dosage for vacuum filtration (%):	
Ferric chloride	3.08
Lime	15.9
Calcium oxide	14.2
Sludge filtration:	
Filter cake:	
Total (tons)	13,048
Moisture (%)	66.4
Volatile solids (%)	45.4
Pounds dry solids per sq. ft. filter area per hr.	3.53
Filter cake per filter hour (tons)	0.87
Average filter cloth operating life (hr.)	176
Sludge filter cake:	
Tons per month incinerated	468
Tons per incinerator hour	0.98
Tons used for soil conditioner	7,430
Incineration:	
Fuel oil used:	
Gal. per ton of filter cake	0.44
Gal. per ton of dry solids	1.32
Gas used:	
Cu. ft. per ton of filter cake	1,254
Cu. ft. per ton of dry solids	3,737
Plant costs ($ per m.g.):	
Operation and maintenance	16.17
Administration	14.94
Total	31.11

came blocked, necessitating the incineration of the cake although there was public demand for it.

The quick burning and high heat characteristics of the scum-laden filter cake required the use of both incinerators, when normally one incinerator could handle the volume of cake burned. Both incinerators were in service during the last six months of 1954. Although some maintenance was needed, it was deferred because both units were needed for incineration purposes and there was no opportunity to shut one down for repairs.

A draft fan broke a vane and was rebuilt, although it would not operate at high speed without undue vibration. A new unit will be installed when operations permit.

Operation data for 1954 are summarized in Table II.

Report on the Operation and Maintenance of the Southerly Sewage Treatment Plant, Cleveland, Ohio, for the Year 1954*

By Walter E. Gerdel, *Superintendent*

General

A portion of the extensive construction program started in 1952 was completed in February. This work involved additional digestion and elutriation equipment, new settling tanks, and new grit-removal facilities. Improvements to the aerators were still under construction at the end of the year. When these facilities are completed the efficiency of the treatment plant will be increased from 65 per cent to 95 per cent, and the capacity will be 68 m.g.d. Facilities for additional sludge handling are now under study.

Sewage treatment and sludge processing were somewhat curtailed because of construction. The activated sludge units were taken out of service in March and not used during the remainder of the year. The elimination of secondary treatment was compensated for to some extent by the excellent performance of the new primary settling tanks.

The metered raw sewage flow averaged 47.8 m.g.d. and was 30 per cent greater than for the previous year. The greater capacity of the new primary settling tanks enabled much higher flows to be taken through the plant than was possible previously.

The flooding of the plant on October 15 and 16 resulted in the bypassing of the entire flow of raw sewage. The flood was attributed to large construction openings in the 8.5-ft. diameter interceptor, which permitted the entrance of excess surface water as a result of abnormal river elevation and storm flow. A considerable number of motors and pumps were submerged. The wash-water basin and pump were flooded and the pump building, blower building, Imhoff building, various connecting tunnels, and the lower portion of the primary tanks pipe gallery were flooded by water flowing into the tunnel system from the new aeration gallery which was under construction.

Sandbagging and portable pumps saved the primary tanks, digesters and sludge concentration units from damage. Power was not completely restored until October 20 and the primary tanks were actually not returned to service until October 23. During this period the treatment plant was completely bypassed.

Recommendations were made to reduce the danger from future floods by providing additional flood protection facilities. The most important recommendation was to transfer all electrical distribution equipment from the basement of the pump building to an upper level. Utilization of two former filter dosing pumps as an emergency pumping station also was planned.

Trouble was experienced in the flooding of both the automatic raw sewage sampler and the settled sewage sampler. The raw sewage sampler will be used to take final effluent samples and the settled sewage will be pumped to the settled sewage sampler which will be relocated.

Grit Removal

Operation of the new comminutor and grit removal equipment was normal. However, the organic return mechanism clogged with rags and other debris. The provision of better inspection and servicing facilities should alleviate this problem. One of the two detritors is drained and cleaned each week, thereby preventing overloading of the revolving rake arms with accumulations of rags.

The unequal removal of grit by the units is apparently due to hydraulic

* For last previous report see This Journal, 27, 8, 982 (Aug., 1955).

conditions of the sewage conduit. A suitable baffle plate, to be installed upstream from the detritors, is expected to correct this condition.

Hand rails were installed along the sides of the detritors where necessary for safety reasons.

The comminutors operated with a minimum of maintenance and with only a little wear of the cutting elements. This favorable experience reflects the desirability of removing grit before comminution.

Primary Treatment

The new primary settling tanks removed an average of 54.9 per cent of the suspended solids and 48.3 per cent of the B.O.D.. In addition, a portion of the digester supernatant was discharged to these units.

The tanks operated satisfactorily, both electrically and mechanically.

Difficulties were experienced with the blowers supplying air for preaeration. The perforated air diffusers in the influent channel are difficult to service which is a factor in the overloading of the blowers.

Aeration Units

The aeration units were taken out of service in March so that construction could begin on lengthening the units from 157 ft. to 392 ft., thereby increasing the detention time from 1.5 hr. to 4 hr. at 22 m.g.d. New swing-type air diffusers are to be installed.

The weirs in the final settling tanks were lowered to permit the handling of increased flow, and considerable painting and other maintenance work was performed.

The Nos. 1 and 2 engines and blowers were completely overhauled by plant personnel. The construction contract for aeration equipment will provide four new engines and blowers. Air filtering facilities were enlarged.

Sludge Digestion

The experimental full-scale operation of the Imhoff tanks as open secondary digesters was continued. These 12 tanks receive supernatant from the primary digesters. Operation was at a constant level with most of the effluent being discharged to the outfall sewer. The 18 floating cover digestion tanks were operated as primary digesters.

Although the volume loading increased only slightly, the solids loading increased considerably as a result of the new primary settling tanks. Sludge was withdrawn in equal volume from both the primary and secondary digesters and filtered on vacuum filters. The secondary digester sludge solids, on a dry weight basis, averaged 6.87 per cent compared with 5.2 per cent for the primary digester sludge. The use of sludge pot ejectors is unsatisfactory and time-consuming.

Gas production averaged 7.23 cu. ft. per pound of volatile solids added, and was approximately 20 per cent greater than during the previous year. During the year a study was made to determine the probable gas production of the secondary digesters. A covered primary digester was loaded with supernatant in a manner similar to the loading of the secondary tanks. Gas production was measured and it was determined that five million cubic feet per month could be obtained from the secondary digesters.

Considerable repair work was done on the digester floating covers, but was not completed.

Large quantities of oil and floating scum appeared on the secondary digesters. The problem requires considerable study, since the quantities of scum and oil are too great for hand removal.

The elutriation unit was not operated during the year. A number of changes in the unit were made either by contract or with municipal forces. It is hoped that satisfactory operation can be obtained.

Sludge Disposal

Sludge was dewatered on vacuum filters directly from the digesters.

TABLE III.—Summary of Operating Data, Southerly Plant, Cleveland, Ohio, for the Year 1954

Item	Average 1954
Raw sewage flow (m.g.d.)	47.8
Detritor grit (cu. ft. per m.g.)	1.78
Per cent volatile	41.2
Flow distribution (%):	
Aeration unit*	7.7
By-passing sec. treat.	92.3
Suspended solids (p.p.m.):	
Raw	192
Primary effluent	87
Removal, primary (%)	54.9
Aerator influent*	92
Aerator effluent	37
Dissolved oxygen (p.p.m.):	
Raw sewage	6.4
Primary tank effluent	5.6
Aerator effluent*	1.0
River above plant	7.3
River below plant	7.1
B.O.D. (p.p.m.):	
Raw	126
Primary tank effluent	65
Removal, primary (%)	48.3
Aeration tank effluent*	23
River above plant	12
River below plant	20
Combined effluent over-all reduction (%):	
Suspended solids	57
B.O.D.	50.8
Sulfates in raw sewage (p.p.m.)	211
Digester operation:	
Raw sludge:	
Volume, total (m.g.)	267.3
Per cent from Easterly plant	76.3
Per cent from Southerly plant	23.7
Dry solids (%)	3.7
Volatile solids (%)	61.9
Primary digested sludge:	
Volume, total (m.g.)	26.4
Dry solids, total (mil. lb)	11.75
Volatile solids, total (mil. lb.)	5.46
Total solids (%)	5.2
Volatile solids (%)	46.6
Alkalinity (p.p.m.)	2,780
pH	7.7
Secondary digested sludge:	
Volume, total (m.g.)	26.4
Total solids (%)	6.87
Volatile solids (%)	46.1
Alkalinity (p.p.m.)	2,990
pH	7.7
Supernatant:	
Volume, total (m.g.)	213.9
Total solids (%)	1.04
Volatile Solids (%)	50
Suspended solids (p.p.m.)	8,330
Gas production:	
Daily production (cu. ft.)	1,020,300
Cu. ft. per lb. volatile solids	7.23
CO_2 (%)	35.6
B.t.u. (gross)	592
Gas utilization (%):	
Wasted	38.4
Digester heating	35.9
Incinerators	18.0
Gas engines*	—
Building heat and misc.	8.0
Vacuum filtration of sludge:	
Filtered, total (m.g.)	51.67
Dry solids, total (mil. lb.)	23.81
Chemicals used (%):	
Ferric chloride	5.54
Lime	19.0
Filter cake production:	
Dry solids, total (tons)	17.15
Solids (%)	26.9
Volatile solids (%)	36.6
Filter rate (lb. dry solids per hr. per sq. ft. filter area)	3.1
Filter cloth life (hr.)	231
Sludge incineration:	
Tons per month, wet	5,207
Tons per incinerator day	88.2
B.t.u. per lb. volatile solids	12,156
Filter cake moisture (%)	73.1
Filter cake, volatile (%)	36.6
Plant costs ($ per m.g.):	
Operation and maintenance	12.93
Administration	14.92
Total	27.85

* Operated only during January and February.

Dosages of ferric chloride (5.54 per cent) and lime (19 per cent) were high compared with operations when the sludge was elutriated. Filter production was good and averaged 3.09 lb. of dry solids per square foot per hour. The Southerly plant receives all the sludge from the Easterly plant for digestion and filtration.

Maintenance was normal. One filter was overhauled, the west horizontal conveyor belt was replaced, and filtrate lagoon drainage piping was revamped.

An average of 88.2 tons of filter cake was burned per incinerator day. The loading was considerably higher than in previous years, again reflecting the

increase in solids removal from the raw sewage. The sludge drying beds were not used during the year.

Water spray cooling of the hot gases leaving the incinerator was discontinued. Considerable repair work was necessary and, for several months, incinerator capacity was insufficient to handle the load. Corrosion of the steel incinerator shell continued unabated. Smoke control was practiced although it was not always satisfactory.

Operation data for 1954 are summarized in Table III.

DIGESTER INSULATION WITH CELLULAR GLASS

To reduce digester size and increase the operating efficiency, the new Steubenville, Ohio, sewage treatment plant wrapped its two digesters in an insulating coat of cellular glass.* The topography at the plant site and the location along the bank of the Ohio River did not permit the covering of the digesters with a mound of earth.

The low heat transmission coefficient of cellular glass has been utilized to increase the insulation of the digester over that experienced with cavity wall construction. The reinforced concrete digester was primed with an asphalt emulsion and the 2-in. blocks of cellular glass were laid on the wall with asphaltic cement (Figure 1). A brick exterior wall was constructed to protect the insulation from physical damage and to complete the insulating job. The two walls are tied together with "tie-to" inserts.

The non-fibrous, all glass insulation is composed of sealed glass cells which are impervious to moisture. Moisture resistance is particularly important since the insulation is buried in the wall and its deterioration would be reflected only in higher heating cost and a lower rate of digestion.

The limited area of the site and the elimination of slope maintenance problems were two factors in the decision to construct insulated digesters. High ground-water conditions along the river precluded construction of the tanks much below grade.

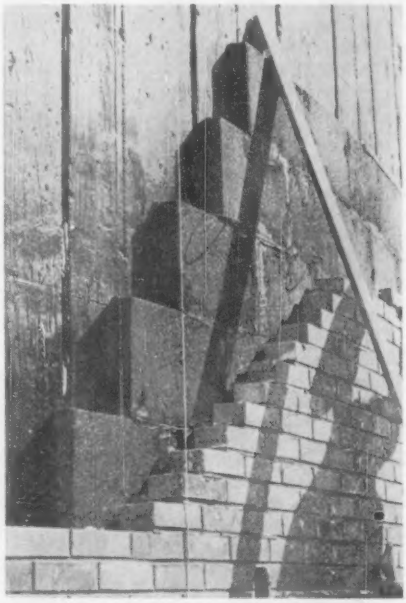

FIGURE 1.—View of tank insulation work sequence of operations.

The 65-ft. diameter digesters will be operated at 100° F. for maximum digestion efficiency. Other units of this 9 m.g.d. plant provide for chlorination, grit removal, primary sedimentation, and sludge dewatering and incineration.

* Foamglas, Pittsburgh Corning Corp.

TIPS AND QUIPS

Dirt Cheap?

A ton of water—collected, purified, stored and delivered to your door—can be purchased for less than a dime. Dirt will cost you more than two dollars per ton.

The same amount of water laden with waste products and pathogenic organisms is conveniently collected at your door, transported away, treated and discharged as a water resource for less than a nickel.

Neoprene Splicing Tape

Weather-resistant neoprene splicing tape can be successfully used to replace standard rubber tape in covering splices in electric lines. Neoprene's chemical properties resist deterioration and make for long-lived splices.

Lubrication Caps

Snap-on caps prevent introduction of foreign matter into bearings by keeping lubrication fittings clean between greasings. Keeping the fittings covered also improves safety and housekeeping, and masking is unnecessary when equipment is sprayed or painted. The caps are available in a range of bright colors which multiply their value. Colors can be used to set up a lubrication schedule, to indicate type of lubricant, and to make it easier to locate inaccessible fittings.

In the development of these snap-on caps natural rubber was ruled out because of its swelling, various plastics were too slippery when greasy to stay on, and paper did not have the elasticity needed. Molded neoprene caps pass all the requirements.

Hairy Problem

Treatment plant operators who are plagued with the problem of tannery hair should be encouraged by the experience of Charles Hicks, Superintendent, Cobourg disposal plant, Cobourg, Ontario, Canada. Superintendent Hicks reports that digester scum in his plant has been effectively controlled by the use of sludge recirculation and digester agitators.

The Cobourg sewage treatment plant has been in operation six years and receives a considerable quantity of hair from a local tannery. A fine revolving screen removes a large portion of the hair, although it is a considerable problem to keep the screen reasonably clean. Even with good operation some hair is pumped to the digester with the primary sludge.

If the accumulation of hair in the digester is not controlled a heavy, matted sludge develops. Fortunately, effective control has been obtained by recirculating the digester contents two or three times each week for a period of three hours. The sludge is pumped from the digester bottom and discharged in the top of the digester, while at the same time the high-speed digester agitator is operated. The agitator normally operates for two hours out of every six.

The scum layer measures only 8 in. and is not matted. Gas production is good and the sludge can be withdrawn readily to the drying beds.

Odors resulting from the tannery wastes are controlled with chlorination of the raw sewage.

Gasket Joint for C. I. Pipe

Cast iron pipe manufactured with a seat for a circular rubber gasket is being produced by the United States Pipe and Foundry Company, Birmingham, Ala. The "Tyton Joint," as it is trademarked, reportedly makes a simple, sturdy and tight joint that has been confirmed in field tests as satisfactory for all services in which cast iron pipe is used.

Figure 1 shows the shape of the gasket and how it fits on the pipe. The gasket is placed in the socket, its inside surface is given a light coating of lubricant and the slightly tapered plain end of the joining pipe is forced into and seated in the socket. The gasket is compressed by the plain end and the joint is made.

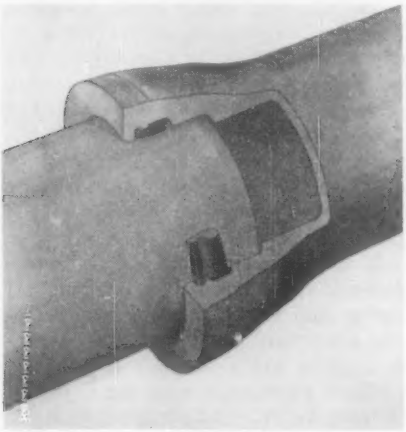

FIGURE 1.—Tyton Joint for cast iron pipe.

Advantages of this joint are similar to the advantages attributed to other joints which do not use caulking materials and don't require the pouring of hot lead or bituminous compounds.

Illustrated information on the assembly of a U. S. Tyton joint on cast-iron pipe is presented in the September 1956 issue of *The U. S. Piper* (U. S. Pipe and Foundry Co., 3300 First Ave., North, Birmingham 2, Ala.). Additional information is available from the same address.

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Remarkable improvements in reducing noise levels are achieved by controlling the key factor—reverberation—with the strategic location of sound-absorptive acoustical material.

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Imagine a millennium in which all kinds of heavy machinery will operate as quietly as a noiseless typewriter. Or more practically, a reduction in noise level which will allow operating personnel to converse in normal tones of voice.

Nebraska Sewage Lagoons

A number of small communities in Nebraska have reported satisfactory operation of sewage lagoons for the primary or secondary treatment of sewage. In addition to Kernie (THIS JOURNAL, **28**, 111, 1326; Nov., 1956), the following communities use lagoons:

City (Nebraska)	Population	Lagoon Acreage
(*a*) PRIMARY LAGOONS		
Ceresco	325	1.55
Duncan	228	1
Gibbon	1,063	8
Glenville	281	1.75
Greenwood	364	3
Johnson	262	1.75
Lodgepole	555	7.3
Loomis	220	1
Plymouth	350	3.6
Potter	421	4.5
Waverly	310	3.33
(*b*) SECONDARY LAGOONS		
Ashton[1]	390	1
Bassett[2]	1,066	2
Bushnell[1]	300	3
Dalton[1]	417	2.5
Greeley[1]	787	1
Scotia[1]	474	1
Minden[3]	2,120	2

[1] Preceded by Imhoff tank.
[2] Preceded by primary sedimentation.
[3] Preceded by primary sedimentation and trickling filter.

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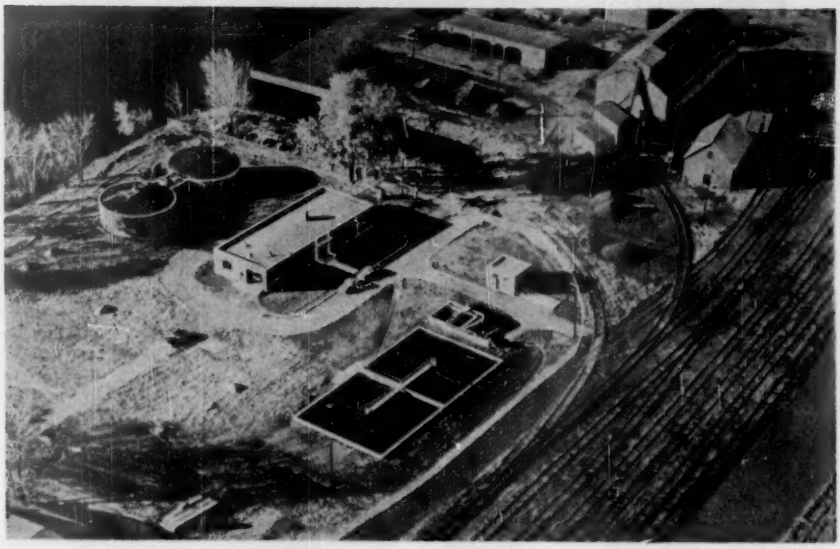

Consulting Engineers: Whitman and Howard — Photo—Dorr-Oliver, Inc.

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S-13

Proceedings of Member Associations

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 1956 Spring Meeting of the New York Sewage and Industrial Wastes Association was held at the Hotel Statler, Buffalo, N. Y., May 28–29, 1956. A total of 132 members and guests were registered.

The technical program opened with a showing of a film, "Every Drop To Drink," covering the London Metropolitan Water Supply. At the luncheon on the opening day the guest speaker was Mr. George H. Shay, Staff Manager, Government Dept., Johns-Manville Corp., New York, N. Y. His topic was "Are Engineers Citizens?"

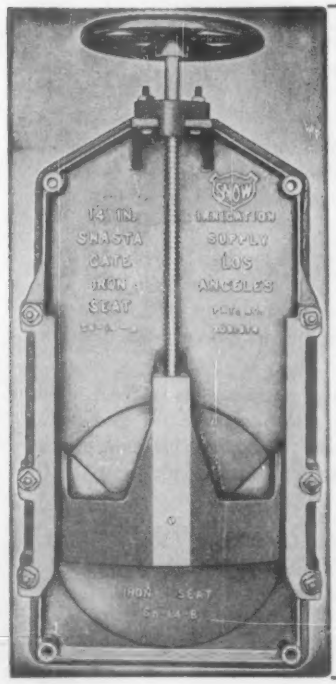
The following technical papers were presented:

"Onondaga County Sewage Problems," by E. F. O'Brien, Partner, O'Brien and Gere, Consulting Engineers, Syracuse, N. Y.

"Design of Industrial Waste Treatment — International Business Machines, Endicott, N. Y.," by L. J. Hosman, Executive Vice-President, Smith, Hinchman and Grylls, Detroit, Mich., and R. J. Keating, Graver Water Conditioning Co., New York, N. Y.

"Preliminary Studies on the Effect of Various Organic Substances on Oxygen Absorption Efficiency," by W. Wesley Eckenfelder, Jr., Associate Professor of Civil Engineering, Manhattan College, New York, N. Y., and Donald T. Lauria and Lawrence W. Raymond, students.

(*Continued on page 508a*)



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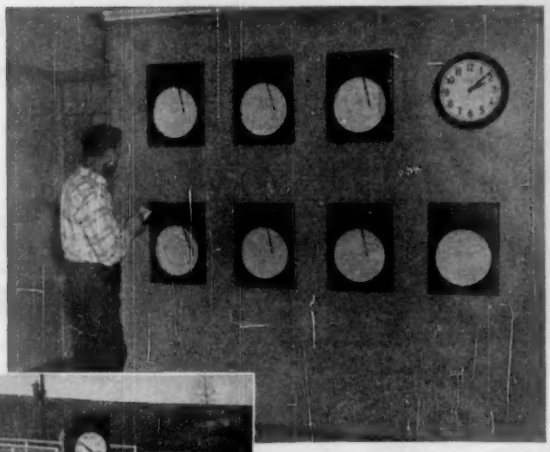
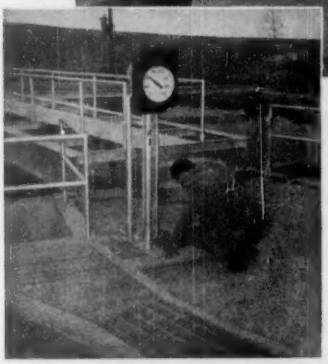


Brown indicating, recording, totalizing flow meters (top) for raw sewage and treated effluents, and (bottom) for air, return sludge flows and excess sludge. Raw incoming sewage is mixed with sponge-like, biologically-active sludge which absorbs pollution matter in the sewage. Sewage then flows to a clarifier, where sludge settles out, and clear, treated water overflows to the river. A portion of the settled sludge is reactivated in an aeration tank and is returned to the system to treat more sewage. Excess sludge is pumped to digesters.



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Brown flow meters indicate, record and totalize flow rates of raw sewage influent, clarified effluents, air, sludge returned to the system, and excess sludge. Orifice plates are used with air flows, Venturi tubes with return and excess sludge flows, and Parshall flumes are used with raw sewage and clarified effluents.

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Brown Parshall flume indicators and air flow recorders are mounted outdoors near clarifiers and aeration tanks at the Biosorption sewage treatment plant in Austin, Texas.

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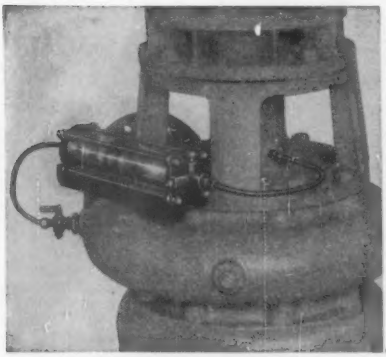

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"Treatment of Plating Wastes for Small Plants," by John W. Furlow and Harry Ribel, Eggly-Furlow, Engineers, Philadelphia, Pa.

"Master Sewage Planning for 1980 at Greece, N. Y.," by Francis J. Cramer, Superintendent of Water and Sewage Treatment, Town of Greece, Rochester, N. Y., and William T. Ingram, Adjunct Professor, New York University College of Engineering and Consulting Engineer, New York, N. Y.

"Suspension of Secondary Treatment at Lackawanna and Blasdell, N. Y., During the Winter Months," by Thaddeus J. Pieczonka, Superintendent of Sewage Treatment, Lackawanna, N. Y.

"The Buffalo Sewage Treatment Plant," by Charles R. Velzy, Nussbaumer, Clarke and Velzy, Inc., New York, N. Y.

The Operators' Breakfast featured a panel discussion on the topic, "The Discharge of Industrial Wastes into Municipal Sewer Systems," moderated by Fredric W. Crane, General Manager, Buffalo Sewer Authority, Buffalo, N. Y. Other panel members were D. B. Stevens, Associate Chemical Engineer, New York Water Pollution Control Board, Albany, N. Y.; R. W. Hess, Coordinator of Pollution Research, National Aniline Div., Allied Chemical and Dye Corp., Buffalo, N. Y.; George F. Fynn, Treatment Plant Superintendent, Buffalo Sewer Authority, Buffalo, N. Y.; Tony Gabbaccia, Lederle Laboratories, Pearl River, N. Y.; and Charles C. Spencer, Consultant, Erie County Dept. of Health, Buffalo, N. Y.

The meeting was concluded with a field trip to the Birds Island treatment works of the Buffalo Sewer Authority.

R. C. SWEENEY,
Executive Secretary

INSTITUTE OF SEWAGE PURIFICATION

The 1956 Annual Conference of the Institute of Sewage Purification was held at Harrogate, England, June 18–22, 1956, and was well attended.

Papers of technical interest included the following:

"Whisky and Industrial Alcohol Distillery Wastes," by C. J. Jackson, The Distillers Co.

"Synthetic Detergents in Relation to the Purification of Sewage; Experiments and Operating Experiences at the Mogden Works," by W. T. Lockett.

"Legal Aspects of Water Pollution," by A. S. Wisdom, Deputy Clerk and Solicitor, Thames Conservancy.

"Thoughts on Biological Filtration," by H. H. Stanbridge.

"High-Rate Activated Sludge Process at the Sewage Treatment Works of Wuppertal-Buchenhofen," by Dipl. Ing. H. Mohle, Baudirektor, Wupperverband, Germany.

By invitation of the Bingley Urban District Council, an inspection trip to the sewage disposal works was organized under the direction of J. R. Brown, Sewage Works Manager. An inspection trip to the Huddersfield Sewage Disposal Works was also arranged under the direction of H. H. Goldthorpe, Chemist and Manager, and members of the staff.

The Institute officers for the coming year are:

President: Charles E. Burke, County Borough of East Ham.
FSIWA Director: Martin Lovett, Wakefield, Yorkshire.
Secretary: W. F. A. Snook, London.

W. F. A. Snook,
Secretary

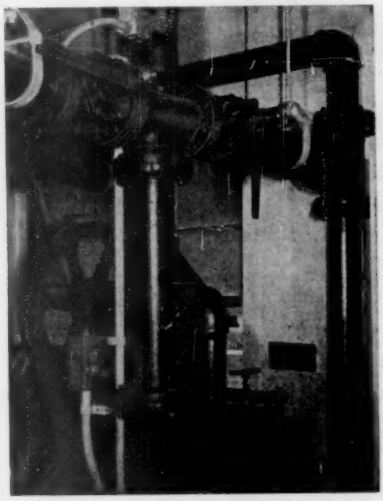
PUERTO RICO WATER AND SEWAGE WORKS ASSOCIATION

The Annual Meeting of the Puerto Rico Water and Sewage Wastes Association was held in June, 1956, and the following officers were elected:

President: Ginés Flaqué Garcés, San Juan.
Vice-President: Enrique Martinó, San Juan.
FSIWA Director: Rafael Domenech, San Juan.
Secretary-Treasurer: Robert J. Auld, San Juan.

A special conference was scheduled on July 2, 1956, to permit the Association Members to meet with Mr. W. H. Wisely, Executive Secretary, American Society of Civil Engineers, in the Aqueduct Authority Auditorium. About 75 engineers, members of the Association and guests were present. Mr. Wisely showed lantern slides of pictures which he had taken of European treatment plants.

Robert J. Auld,
Secretary-Treasurer



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